H. G. Stewart

Order *of* Manitoba Public Utilities Commission *and* Report

Investigation for Stray Electric Currents in the City of Winnipeg and in Adjoining Municipalities

To H. A. ROBSON, Esq., K.C., Public Utilities Commissioner of the Province of Manitoba, Canada
By ALBERT F. GANZ, Consulting Engineer

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Report

Investigation for Stray Electric Currents in the City of Winnipeg and in Adjoining Municipalities

TO

H. A. Robson, Esq., K.C., Public Utilities Commissioner of the Province of Manitoba, Canada

BY

Albert F. Ganz, Consulting Engineer

1915

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File No. 112
Order No. 261

MANITOBA

THE PUBLIC UTILITIES COMMISSION

Thursday, the 22nd of July, 1915

In the matter of an application by the City of Winnipeg to compel the Winnipeg Electric Railway Company to establish proper measures of prevention of damage to underground cables and mains by electrolysis by electrical currents from the electric railway system of the company.

Upon reading an application by the City of Winnipeg, dated the 24th day of July, A.D. 1913, after notice to the said Company for an order:

(1) To compel the Winnipeg Electric Railway Company, in the operation of its street railway system in the City of Winnipeg, to install and establish a proper system of bonding and cross-bonding of the rails in order to make the rails a continuous conductor, and thus secure a good and proper return path for the electric current, and to properly rebond all defective bonding now or hereafter existing;

(2) to properly bond and connect said rails and track to the stations of the company;

(3) to install a sufficient number of substations at different points of the system, with a view to diminishing the amount of current to be returned through the rails in the centre of the city;

(4) to establish and institute a system of special bonding and cross-bonding work at intersections;

(5) to establish and conduct a proper system of inspection of track returns in the construction and extension, as well as in the operation of the said street railway system;

(6) to discontinue the practice of connecting the company's system with the Government telephone cables, and to remove all such connections as may now or hereafter exist;

(7) to discontinue the use of ground plates at sides of bridges for carrying return currents from one side of a river bank to the other, and generally adopt such means and take such precautions as may from time to time be necessary to ensure the return along a single path, of electric current to the station at which it is generated, and to avoid and prevent the escape, diversion or roaming of such current on its return, through other than the rails and conductors provided for that purpose.

Upon reading an application, dated June 26th, 1914, from the Greater Winnipeg Water District, that consideration be given the matter of electrolysis, in so far as it may in any way affect the proposed pipe line of the Greater Winnipeg Water District, and the distribution system or systems, that may be installed in the various municipalities or parts of municipalities forming the district;

Upon reading the briefs submitted by the City of Winnipeg on June 15th, 1914, outlining specific cases of damage to their cables and water mains, which damage, it is contended, was caused by electrolysis from the stray currents of the Winnipeg Electric Railway;

Upon reading the briefs submitted by the Manitoba Government Telephone Commission on June 12th, 1914, outlining specific damage to their underground cables in the said city, which damage, it is contended, was caused by electrolysis from stray currents of the Winnipeg Electric Railway Company;

Upon reading the brief submitted by the Winnipeg Electric Railway Company on June 15th, 1914, maintaining that every due precaution was being taken by that company to mitigate all damage due to electrolysis;

And whereas it was expedient to appoint an electrical engineer independent of the parties, for the purpose of investigating, reporting and advising upon the matters involved in the above applications, and consequently, after due notice to the said city and company, Albert F. Ganz, Esq., was appointed and authorized to investigate, report and advise upon the matters involved in or pertaining to the protection of the property of the parties above named from electrolysis by stray electrical currents from the Winnipeg Electric Railway Company's system;

And whereas the above Albert F. Ganz., Esq., did, after notice to and after hearing at various times the representatives of all the said parties, investigate, consider and report on the aforementioned matters. and did make recommendations for the mitigation of damage by electrolysis resulting from such stray electrical currents, and the said report having been filed and considered by this Commission, as part of the evidence and material on this application by virtue of "The Public Utilities Act";

And whereas the aforesaid parties, by their solicitors, officers and employees, have been heard at various times heretofore on the subject of the said application, and investigation and of this order,

It is ordered—

(1) Every rail joint in the tracks of the electric railway system of the said company shall be so constructed and maintained that its resistance does not exceed the resistance of eight (8) feet of continuous rail. Tests of the resistance of rail joints shall be made and recorded

at least once every year, and when defective joints are found they shall be promptly repaired.

(2) The two rails of every single track in the said system, and the four rails of every double track, shall be maintained adequately cross-bonded, and all special track work shall be spanned by copper wire jumpers of adequate current-carrying capacity.

(3) All conductors which connect the tracks of the electric railways in the said system to the direct-current supply stations shall be insulated from the earth.

(4) No metallic connections shall be permitted by the said Company in its system between water, gas or other underground pipes and any part of the electric circuit of the electric railway.

(5) The rails or other metallic conductors forming parts of current-carrying electric circuits of the said electric railway system, which are not insulated from earth, shall be designed, constructed, operated and maintained, so that the average potential difference during any ten (10) consecutive minutes between any two points one thousand (1000) feet or less apart on said rails or other metallic conductors will not exceed one (1) volt, and, further, so that the average potential difference during any ten (10) consecutive minutes between any two points more than one thousand (1000) feet apart on sail rails or other metallic conductors within the area comprised by Winnipeg (including Elmwood) and St. Boniface, will not exceed seven (7) volts (approximately the value adopted by the British Board of Trade).

On account of the concentration and great importance of the underground structures in the neighborhood of the corner of Portage avenue and Main street, Winnipeg, all feeders connecting to the tracks within a radius of fifteen hundred (1500) feet from the said corner shall be so proportioned as to maintain their connection points in the tracks at the same or slightly lower potential than the tracks at the said corner during peak load. Owing to the proximity of the city water works, and of the important water main leading to the said works, to substation No. 8, on Logan avenue, at McPhillips street, all feeders from the said station to the tracks shall be proportioned for substantially the same voltage drop during peak load. The track voltage requirements of this recommendation are to apply only to normal operating conditions on a business day, and not to occasional abnormal conditions in street railway traffic brought about for example by fires, storms, or holiday crowds. If at any time such difference of potential exceeds the above the company shall take immediate steps to bring it below such limit.

(6) Potential wires insulated from earth shall be installed by the company in the district of every substation of the company whereby contact may be made to the tracks at each point where a return feeder from this station connects to the tracks, at the feeding limits of each substation on the principal track lines where these terminate within the limits of Winnipeg (including Elmwood) and St. Boniface, and at

the points where principal track lines cross the limits comprising Winnipeg (including Elmwood) and St. Boniface. These potential wires shall terminate in the substations in such a way that they can be conveniently connected to an indicating volt-meter and to a 24-hour recording voltmeter. One voltmeter of each type shall be provided for each direct-current supply station, so arranged that the potential difference between any two of the above described points in the track system can be measured or automatically recorded. A potential wire shall also be connected to a nearby water pipe by means of which the potential of the negative busbar referred to earth may be measured or recorded.

(7) By means of the potential wires and voltmeters provided for in clause (6) above, the following measurements and records shall be obtained: The average potential difference between the tracks at a feeder connection point near the substation and each other feeder connection point, shall be determined from readings of the indicating voltmeter taken and recorded for a period of about five minutes during the peak load hour, once every month. From such test the point in the tracks which is at the lowest potential shall be determined. A twenty-four hour record of the potential difference between each point in the tracks at the feeding limits or at the city boundary and the tracks at the point of lowest potential shall then be determined once every month, on a normal business day. The potential difference between the negative busbar and a nearby city water pipe shall also be obtained at least once every day during peak load. If this potential difference should fall at any time to such a low value as to indicate grounding of the negative bus-bar, steps shall be taken by the said company to remove the ground connection.

(8) All records of the tests described in the foregoing clauses, as well as the recording meters and meter charts shall be open to inspection from time to time by an authorized representative of the Commission. True copies of all records, as soon as completed, shall be forwarded by the company, to this Commission, as also recording meter charts, within twenty-four hours after the taking of such records and charts.

(9) After the work required by clauses 1, 2, 3, 4, 5 and 6 of this order has been done, in every case all drainage connections from underground lead cable sheaths to railway return circuit in Winnipeg, shall in every instance be opened and kept open, and tests of the potential of these cable sheaths referred to other structures and of current on the cable sheaths, shall (on twenty-four hours' written notice to the owner of such cable sheaths of the time and place at which the test is to be made), be made by the company to determine the electrolysis condition of such cable sheaths. If, in such case, cable sheaths shall be found to require additional protection, a limited amount of electrical drainage may be applied by the company upon application to this Commission on notice to the owner of the cable sheath, and subject to such directions as may be then given by this Commission. Such drainage connections must be arranged to apply equally to all of the underground cable

systems, so as to avoid setting up serious potential differences between the lead sheaths of the different cable systems. They must also be so arranged and maintained as to drain off the least current consistent with the complete protection of the cables and without setting up dangerous voltages to other underground structures. A suitable fuse, a knife switch, and an ammeter, shall be installed in each drainage connection, and daily readings of the current drained from the cables during the peak load hour shall be obtained and recorded. The drainage connection must be opened whenever the station is not in operation.

(10) In future constructions and reconstructions of direct current electric railways employing the running tracks as part of the electric circuit, such track construction shall be employed, in addition to that already required by the previous clauses, as will give the greatest practicable resistance between tracks and earth for the existing conditions. Without limiting the foregoing this must be done particularly where such railways cross or run close to underground pipe or cable lines.

NOTE.—Clauses numbers 1, 2, 3 and 4 of the foregoing are to apply to the railway lines of the company, as far as these lines are supplied with direct current from the sub-stations located within or near the limits of Winnipeg. Clauses numbers 5, 6 and 7, however, are not made to apply to the lines extending beyond the limits of Winnipeg and St. Boniface, because these lines are generally located on country roads where the tracks can be substantially insulated from ground, and where there are at present no underground structures which could be affected by electrolysis.

(11) In future constructions or reconstructions by the company (within the Province of Manitoba, but excepting the cities of Winnipeg and St. Boniface, which are covered by the previous clauses) of direct current electric railways employing the running tracks as part of the electric circuit, clauses numbers 1, 2, 3 and 4 shall be complied with by the company, and, in addition, such track construction shall be employed by the company as will give the greatest practicable resistance between tracks and earth in the existing conditions. If such electric railways operate within limits where there is valuable underground property which may be endangered by electrolysis, the track voltage limitations, the potential wires for measuring these voltages, and the periodic tests of these voltages, as required in clauses numbers 6, 7 and 8 hereof, shall be complied with within the limits affected.

(12) That the Winnipeg Electric Railway Company shall prosecute the herein specified work and equipment to completion by midnight of the 31st day of October, A.D. 1916. That immediate action shall be taken by the company to prosecute the work and that monthy progress reports be delivered by the company to this Commission. The work accomplished from month to month, after this order goes into effect, must be such as to show that all diligence is being wrought to execute this order. In the event of want of diligence from month to month, as aforesaid, by the company in carrying out the work hereby ordered the city may apply to this Commission for the imposition of penalty for delay or for such other order as may appear proper.

The company shall, in the construction, maintenance and operation of its electric railway system, continuously observe and perform all the directions contained in this order.

(13) That in the design and construction of the insulated return feeder system as required under this order, the Winnipeg Electric Railway Company shall employ a safety factor of 1.5, that is to say in determining the amount of copper required in the return feeders to reduce the voltage drop to the limit prescribed under clause 5, which will be estimated theoretically under the normal peak load conditions, such amount shall be increased by fifty per cent. of itself to insure the fulfilment of the requirements under varying operating conditions.

(14) That, in the installation of insulated return feeders and potential wires along Portage avenue, from Victoria street to the St. James substation, and on Main street from Graham avenue, to Sutherland avenue, all wires and cables shall be placed underground in conduits of the company laid in streets as either already existing, or (as to Main street) to be constructed according to the plans heretofore approved for that purpose by the council of the said City of Winnipeg.

(15) In the event of the herein specified work and equipment not being completed by midnight of October 31st, 1916, the Winnipeg Electric Railway Company shall pay a penalty of fifty dollars ($50.00) for each and every day that the default continues after the specified time.

It is ordered that the question of the costs of and incidental to the said investigation and report be reserved for subsequent order.

This order shall go into effect on the twenty-first day after its date.

H. A. Robson,
Commissioner.

Entered July 22, 1915.
Book No. 1—Folio 381.

A. W. Smith,
Secretary.

(Seal).

LETTER OF TRANSMITTAL.

CASTLE POINT, Hoboken, N.J.,
March 29, 1915.

H. A. ROBSON, Esq., K.C.,
Public Utilities Commissioner,
Winnipeg, Manitoba.

Dear Sir,—I beg to submit herewith my report on the investigation for electrolysis and other dangers due to stray currents in the City of Winnipeg, Manitoba, and in adjoining municipalities, which investigation I have made in accordance with your verbal instructions, and with your order of June 24, 1914.

The City of St. Boniface was specifically included in your order, but I have not made any investigation relating to underground structures in St. Boniface according to later verbal instructions from you. I have, however, included tests on the electric railway tracks in St. Boniface, because this railway is part of the Winnipeg system and stray currents from these tracks would affect the underground structures of the City of Winnipeg.

I have also received copies of tests, reports and other data, filed with the formal applications and briefs, and also such additional data as have been submitted by the city electrical department, by the Winnipeg Electric Railway Company, and by the Manitoba Government Telephone Commission. These reports and data are not reproduced in this report, but all of the information contained therein has been given careful consideration, and has given me a good general idea of the electrolysis situation in Winnipeg. To complete the information in regard to the entire situation, however, I found it necessary to have additional tests made on the electric railway system and on the underground water piping and cable systems in Winnipeg. I was personally present in Winnipeg supervising these tests between June 21st and July 12th, and between October 20th and November 6th. The actual field work was carried on by representatives of the city electrical department, of the Manitoba Government Telephone Commission, and of the Winnipeg Electric Railway Company; and I was assisted in the supervision of these tests by Messrs. W. E. Skinner and George L. Guy, representing your Commission. Field tests laid out by me were also made under the supervision of Messrs. Skinner and Guy during July, August and September, and after I left Winnipeg in November.

I wish to acknowledge the valuable assistance which I received during this investigation from Messrs. Skinner and Guy, and also from representatives of the city electrical department, the Manitoba Government Telephone Commission and the Winnipeg Electric Railway Company, and to express my appreciation of the co-operation and the excellent facilities afforded me by all of the interests concerned.

The following report is divided into three sections and an appendix. The first section contains copies of the applications and briefs relating to this investigation which have been filed with your Commission by the various interests concerned, and a copy of your order appointing me to make the investigation. The second section contains a summary of the investigation relating to Winnipeg, with recommendations, and a report relating to the Greater Winnipeg Water District and to municipalities adjoining Winnipeg. The third section contains the detailed report, comprising a chapter on causes and effects of stray currents and remedial measures, and the detailed results of the investigation in Winnipeg. The appendix consists of a copy of my preliminary report on the investigation for electrolysis and the application of temporary remedial measures applied to the underground cable systems in Winnipeg, dated November 17, 1914.

Respectfully submitted,

ALBERT F. GANZ.

SECTION I.

COPIES OF APPLICATIONS, ORDER AUTHORIZING INVESTIGATION, AND BRIEFS AND LETTERS FILED WITH COMMISSION:

Application of the City of Winnipeg, dated July 24, 1913;

Application of the Greater Winnipeg Water District, dated June 26, 1914;

Order of Commission authorizing investigation, entered June 24, 1914;

Brief filed by City of Winnipeg, dated June 15, 1914;

Letter filed by City of Winnipeg relating to gas leakage, dated June 24, 1914;

Brief filed by Manitoba Government Telephone Commission, dated June 12, 1914;

Brief filed by Winnipeg Electric Railway Co., dated June 15, 1914.

APPLICATION OF THE CITY OF WINNIPEG.

THE PUBLIC UTILITIES COMMISSION.

In the matter of an application by the City of Winnipeg to compel the Winnipeg Electric Railway Company to establish a proper system of street railway bonding to prevent damage to underground cables and mains by electrolysis.

Take notice that an application will be made before the Public Utility Commissioner, at his chambers, in the Somerset bldg., on Portage avenue, in the City of Winnipeg, on Tuesday, the fifth day of August, A.D. 1913, at the hour of 10.30 o'clock in the forenoon, or so soon thereafter as the application can be heard, for an order to compel the Winnipeg Electric Railway Company, in the operation of its street railway system in the City of Winnipeg, to instal and establish a proper system of bonding and cross-bonding of the rails in order to make the rails a continuous conductor, and thus secure a good and proper return path for the electric current, and to properly rebond all defective bonding now or hereafter existing;

(2) to properly bond and connect said rails and track to the stations of the company;

(3) to instal a sufficient number of sub-stations at different points of the system, with a view to diminishing the amount of current to be returned through the rails in the centre of the city;

(4) to establish and institute a system of special bonding and cross-bonding work at intersections;

(5) to establish and conduct a proper system of inspection of track returns in the construction and extension, as well as in the operation of the said street railway system;

(6) to discontinue the practice of connecting the company's system with the Government Telephone cables, and to remove all such connection as may now or hereafter exist;

(7) to discontinue the use of ground plates at sides of bridges for carrying return currents from one side of a river bank to the other, and generally to adopt such means and take such precautions as may from time to time be necessary to ensure the return along a single path of electric current to the station at which it is generated, and to avoid and prevent the escape, diversion or roaming of such current on its return, upon the following (among other) grounds:—

1. The electric current used by the Winnipeg Electric Railway Company for operating its street car service is distributed over the city from the generating plant by trolley wires, and passes from the trolley wires through the car motors to the rails and returns to the generators through the rails;

2. The City of Winnipeg owns and operates in the City of Winnipeg a system of water works and mater mains, which mains are laid all over the city, and in some places run parallel with and are in the neighborhood of the rails of the said railway company;

3. The City of Winnipeg also owns and operates a hydro-electric power plant and an electrical system, and supplies electric current to the citizens of Winnipeg, for light and power purposes; and in connection therewith, owns and operates an underground conduit system for the electrical cables of the city light and power department, which cables are laid in the same districts in which the street railway system of the Winnipeg Electric Railway Company is laid and operated;

4. In connection with said electrical system of the City of Winnipeg the city owns and operates a police and fire alarm system for the city;

5. The Manitoba Government owns and operates in the City of Winnipeg a telephone system, and in connection therewith owns and operates an underground system of lead covered electrical cables, which are also laid and operated in the districts in which the street railway system of the Winnipeg Electric Railway Company is laid and operated, and said cables are in many cases parallel to and in close proximity to the rails of the Winnipeg Electric Railway Company, and in some cases are bonded thereto;

6. The composition of the soil of the City of Winnipeg is such that it is a good conductor of electricity, and in which electrolysis will occur; extra present precautions are therefore necessary to confine the current to a single and continuous path in returning to the generator, so as to avoid the straying thereof into the earth and thence to other conductors embedded in the earth, and thereby causing electrolysis when leaving such other conductors on its way to return to the generator;

7. The rails of the Winnipeg Electric Railway Company which are used as the return path for said current are laid in lengths, do not provide a continuous path for said current, and cannot provide such continuous path unless extra precaution is taken to specially bond and rebond the same, so as to confine the current thereto;

8. Owing to the defective bonding of said rails (used by the railway company as the return path for said current) the current escapes therefrom into the earth and thence into the water mains and underground lead cables of the City of Winnipeg, and has considerably damaged and is doing considerable damage to said water mains and cables;

9. Owing to the damage done to the water mains and to the underground cables of the city, the city's water system, light and power system, and police and fire alarm system are being materially affected and are liable to be, at any time, completely disorganized;

10. The system of bonding the rails of the railway company to the Manitoba Government telephone cables is bad, and operates against confining the return current to a single path;

11. The system of using ground plates at sides of bridges for carrying return currents from one side of a river bank to the other is bad;

12. Owing to the fact that the City of Winnipeg has spent and is spending large sums of money in paving the streets on which the railway system of the company is and will hereafter be operated, and under which the city has laid and will hereafter lay its water mains and its underground cables, it is of the greatest importance that the work of bonding and rebonding of said rails should be most thoroughly and efficiently done in the first instance, and that a most close and thorough system of inspecting such work should be instituted and carried out;

And further take notice that upon said application will be read:

(1) Report of L. A. Herdt made to the Board of Control and dated 22nd April, 1909, and exhibits attached thereto;

(2) Report of Frank Allen, on the damage to the water mains of the city, dated 1st December, 1906;

(3) Report of W. Hatten to city engineer on breaks in water mains;

(4) Copy report of city electrician to the Board of Control, dated 28th April, 1907;

(5) Copy report of city electrician to the Board of Control, dated 15th November, 1907;

(6) Copy report of city electrician to the Board of Control, dated 28th April, 1908;

(7) Copy report of city electrician to the Board of Control, dated 23rd June, 1908;

(8) Copy report of city electrician to the Board of Control, dated 23rd October, 1908;

(9) Copy report city electrician to the Board of Control, on city mains, dated 24th November, 1908;

(10) Copy of report of city electrician to the Fire, Water and Light Committee, dated 14th December, 1908;

(11) Report of city electrician to Board of Control on damage to water mains, dated 29th December, 1909;

(12) Report of city electrician to Board of Control re damage to water main by electrolysis, dated 28th February, 1910;

(13) Statement of claim, Winnipeg v. Winnipeg Electric, issued 17th February, 1912;

(14) Report of L. A. Herdt to the Board of Control, dated 23rd January, 1913;

(15) Report of city electrician to Board of Control, dated 8th May, 1913;

(16) Correspondence between the city and the different officials thereof and the Winnipeg Electric Railway Company;

(17) Such further and other material as counsel may advise.

Dated the 24th day of July, 1913.

THEO. A. HUNT,
Solicitor for the City of Winnipeg.

To the Winnipeg Electric Railway Company.

APPLICATION OF THE GREATER WINNIPEG WATER DISTRICT.

WINNIPEG, June 26, 1914.

H. A. ROBSON, Esq.,
Chairman, Public Utility Commission, City.

Dear Sir,—On behalf of the Greater Winnipeg Water District I desire to make application to you that, when considering the matter of electrolysis, whether in general, as it affects the whole question of iron water pipe, or in particular with reference to the proposed style of construction for the electric railway about to be built from Winnipeg to Transcona, that you will consider the matter, in so far as it may in any way affect the proposed pipe line of the Greater Winnipeg Water District, and the distribution system or systems that would be necessary to instal in the various municipalities or parts of municipalities forming the district.

Yours truly,

J. G. HARVEY.

ORDER OF COMMISSION AUTHORIZING INVESTIGATION.

File No. 112—*Order No.* 134.

WEDNESDAY, the 24th day of June, A.D. 1914.

MANITOBA PUBLIC UTILITIES COMMISSION.

In the matter of a pending complaint by the City of Winnipeg against the Winnipeg Electric Railway Company, regarding injury to water-mains by escaped electric currents.

For the purpose of hearing and determining the said application—

It is ordered that Albert F. Ganz, Esquire, be and he is hereby appointed and authorized to investigate and report upon all matters involved in or pertaining to the said application;

And it is further ordered, upon the initiative of this Commission, that the said Albert F. Ganz, Esquire, be and he is hereby appointed to investigate and report upon the matter of protection from electrolysis by stray currents from electric traction systems in St. Boniface, Transcona and the municipalities adjacent to Winnipeg.

H. A. ROBSON,
Commissioner.

Entered June 24, 1914.
Book No. 1—Folio 224.

A. W. SMITH,
Secretary.

(Seal)

BRIEF FILED BY CITY OF WINNIPEG.

RE APPLICATION CITY OF WINNIPEG VS. WINNIPEG ELECTRIC RLY. CO.

In the matter of electrolysis.

To H. A. Robson, Esq.,
Public Utility Commissioner, Winnipeg.

The applicants' case in the above matter is as follows:

1. The water mains of the applicants having been very seriously damaged by stray currents of the Winnipeg Electric Railway Company from time to time, and upon numerous reports being made by the city electrician to the committees and the city council thereon, the city brought an action against the company.

2. Under date of May 13th, 1906, Professor Frank Allen, of the physicists department, University of Manitoba, was requested by the city to investigate and report on the damage already caused and on the method of bonding and operation as practised by the railway company. Professor Allen reported to the city, on the date of December 1st, 1906, a copy of which report is on file in the office of the Commission.

3. The damage continuing and increasing resulted in the city council, by resolution dated January 5th, 1909, appointing Professor L. A. Herdt, of McGill University, "to report upon the electrical conditions existing in the City of Winnipeg" in the above matter. Professor Herdt personally visited the city and superintended exhaustive tests, made surveys and procured other data, and ultimately reported to the city council on June 22nd, 1909, a copy of which report is on file in the Commission office.

4. The findings of Professor Herdt were acted upon by the Winnipeg Electric Railway Company in part, although there were certain recommendations in the report which it is claimed by the city to be vital and which were not observed. These are as follows:

(*a*) Undue delay occurred in rebonding tracks that were improperly bonded, notably those in Elmwood and River Park;

(*b*) That the company does not maintain its roadbed, rails and return conductors in a high state of efficiency through a rigid inspection of the track returns, as set forth on the last page of Professor Herdt's report;

(*c*) That track returns are not under test at all times;

(*d*) It is claimed by the city that it was understood at the time the report was formulated that recording instruments, similar to those required by the British Board of Trade regulations, would

be installed at each substation, together with the necessary pilot wires leading therefrom to the remote ends of the various tracks fed therefrom, and that the company has, owing to the lack of these, been unable to determine the condition of its tracks or the drop of potential in the same under varying conditions of load, and that there are not under present conditions any adequate means by which the city can ascertain or consult records of the drop in potential at different points of the railway system, as recommended by Professor Herdt on the last page of his report.

5. At the time of the investigation of Professor Herdt the only underground cables existing were those the property of the Manitoba Government and Telephone Commission. Since that date the Telephone Commission has made very great extensions to its underground cable system, and in addition very extensive underground cable systems have been installed by the city in connection with its light and power distribution; the city has also installed a very extensive underground and aerial cable system for its file and police telegraph systems, and, further, there has been installed a considerable amount of underground cable by the Winnipeg Electric Railway Company in connection with its light and power systems, extending from the Mill street substation to the Assiniboia steam plant, and also to the St. James substation.

6. It is claimed by the city that, under present conditions, the lead sheaths of its various cable systems, also its high pressure and domestic water pipe systems, are carrying stray currents of the Winnipeg Electric Railway Company's railway system in various directions, and are exposed to danger thereby, and it is also claimed that, owing to the large amount of underground cables installed by the city, the telephone Commission and the Winnipeg Electric Railway Company, that these with the foregoing form auxiliary negative returns to the railway system with the following results:—

(*a*) The presence of these numerous underground structures renders it more difficult to ascertain the normal drop in potential in the rails of the street railway system;

(*b*) That the presence of stray currents in the city's fire and police telegraph cable sheaths is liable to be exceedingly injurious to the same by reason of a large proportion of the cables being of small cross-section;

(*c*) That potential differences exist between the various cables, and between such cables and other underground structures, and the railway tracks;

(*d*) That the lead sheath cables of the various interests are liable to be injuriously affected by the intermittent operation of some of the substation railway equipments of the Winnipeg Electric Railway Company as by reason of such, the direction of the flow of current in the lead sheaths of cables and other under-

ground structures is reversed, making it almost impossible under present conditions for the owners to adequately protect the same.

7. The applicants claim:—

(*a*) That the recommendations of Professor Herdt, in his report of 1909, are inadequate to deal with the present conditions, owing to the very considerable increase in street railway traffic and the additional mileage of track installed both inside of the city limits and outside of the same, and that therefore additional measures of protection are necessary;

(*b*) That new danger zones at present exist in the vicinity of various substations, as shown by potential surveys submitted herewith;

(*c*) That new cases of electrolytic damage have actually taken place at the following points, by reason of the existence of such local danger zones and from other causes, same being as follows:

(1) Destruction of ¾-inch lead service from the city's domestic water main, Pembina street, near the Winnipeg Electric Railway Company's substation; this pipe was laid September 7th, 1911, broke down December 26th, 1912; voltmeter readings taken at the time show that the water main was from 5 to 16 volts positive to the negative busbar of the above substation, the readings usually running from 9 to 12 volts; it is claimed by the company, in connection with the above, that it was entirely due to the bad state of the pavement on Pembina street, north of the substation; the city claims that the company was negligent in that, knowing the condition of the said pavement and its track returns, it did not take measures to run negative feeders from the substation to the district beyond the alleged bad piece of pavement, and that the only negative returns at the time existing were merely run out of the substation and tapped the rails outside the building.

(2) The breakdown of a city lead water service on Portage avenue a little to the west of Raglan road; this occurred on or about the 2nd of November, 1911; polarity readings taken about the latter date showed the pipe to be 11.2 volts positive to the railway rails; preceding the above the section of same water service, owned by the property owner, broke down on May 1st, 1911; this pipe was laid July 9, 1907; it is claimed that this damage was due to lack of negative returns from the St. James substation to east of the subway; that there was excessive drop in potential between the St. James substation and the easterly limits of the zone supplied by such substation, augmented by the single track in and through the St. James subway; this is further borne out by the fact that a breakdown of the Telephone Commissions cable at Portage and Strathcona, on or about July

29th, 1912; that the Telephone Commission report having found their cables to be 40 volts positive to the street railway tracks and the city's water-main at that point.

(3) A breakdown of the city lead water service on Argyle street, near the Canadian Pacific Railway Company's tracks, same being installed in November, 1906, and broke down on the 1st of August, 1912; this was found to be very badly corroded; it is claimed by the city, in this connection, that at the time of the breakdown railway currents were flowing from the street railway tracks to the water-mains, and from thence to the city's lead-covered 13,000 volt cable on Sutherland avenue, and that it was leaving these cables at Main and Sutherland and flowed north to the Main and Athol substation; it is claimed that there were not sufficient negative feeders connecting the Elmwood district to the east of the Red River with the Main and Athol substation, which at that time (1912) fed the Elmwood district tracks.

(4) Electrolytic damage to city's fire and police telegraph cable in manhole at Pembina and Corydon, on or about May 10th, 1913, the cable having been laid the summer previous to that date, a hole was eaten through lead sheath, admitting water to conductors city cable 0.2 volt positive to Manitoba Government cables in same manhole; piece of affected cable can be produced.

(5) Damage to city's iron service lateral used for carrying the city's fire alarm underground cable into the company's Mill street substation, same being very badly corroded by stray currents; this lateral was laid in 1912.

8. The city submits herewith, as showing the necessity for adequate negative returns and recording instruments at each of the substations connected to distant points of the tracks, a map or plan giving readings between water-mains, cables and tracks in the vicinity of the Logan avenue substation. The management of the railway company, on being informed of these conditions, stated the same to be due to bad connections between the rails and the negative feeders opposite the substation; even allowing for this and the subsequent cutting of certain bonding cables on McPhillips street, which were first discovered by the city electrical department, there are still conditions existing in this vicinity that call for adequate relief. It is affirmed by the city that had the company provided itself with the recording instruments above mentioned, they would have had instant notification of the above breaks in their track returns and also of the additional breaks that occurred subsequently.

9. The necessity for track returns being under constant test is also shown by the following incident:—On or about January 20th, 1913, slight shocks were experienced by the city's cablemen when in contact with the aerial fire and police telegraph cable and messenger

crossing Louise Bridge. (The aerial cable at the time being in contact with an underground cable on Higgins avenue.) Tests were made on January 21st, 1913, and the cable was found to be 10 to 12 volts negative to the messenger. Tests were subsequently made with the bond tester and broken bonds discovered in all rails immediately south of the point where the negative feeder crossing the bridge was connected to the track. These broken bonds rendered the negative feeder practically useless, the aerial cable messenger was carrying return current from the north to the south side of the Louse Bridge, and thence by the underground cables it was carried towards the railway substation.

10. It is also claimed by the city that the aerial cables of its fire and police telegraph system are liable to damage by reason of their small size (the majority of them being .5 inches in diameter) and consequent limited carrying capacity of the lead sheath. These cables are of necessity grounded by ground rods at points indicated on the map on file in the office of the Commission, and tests indicate that the cable is receiving current from car tracks and water-mains at points distant from street railway substations and delivering it back to earth at points near the substations.

11. It is also claimed by the city that, in view of the presence of escaping illuminating gas in various manholes of underground conduit systems, that the danger of explosion is accentuated by reason of the lead cable sheaths carrying stray railway currents and of the difference of potential existing between such cable sheaths and between the same and other underground structures.

12. The city would bring to the notice of the Commission the character of its fire service water works piping system, and the extremely important duty performed thereby. It has invariably been found that breaks on the domestic water-pipe system manifest themselves at the time of prolonged maintenance of extra high pressure during a fire. With the extra high pressure carried during fires on the special mains of the fire service water works system, same being approximately 200 pounds to the square inch, the danger of interruption of service, undermining of pavements, etc., is very great should these mains be weakened by electrolytic action.

It is also claimed by the city that its water-mains have suffered very extensive damage by reason of escaping currents from the operation of the Winnipeg Electric Railway Company's electric railway system, and further that this damage is spread over a wide area. It is claimed that the water mains of the applicants have been weakened structurally within a wide area by reason of such action, and that they have been and are breaking down at numerous points from time to time ever since the remedial measures were undertaken by the company, as is evidenced by the list of cases following:

Points at which breakdowns have occurred on the city's domestic water mains subsequent to Professor Herdt's report and within old danger zones:

Date	Structure Damaged	Location	Remarks
July 23/09	Domestic water main, 6″	N.E. corner Portage and Smith	Pipe eaten through
Aug. 4/09	Domestic water main, 8″	Opposite 643 Main	Pipe badly pitted
Aug. 18/09	Domestic water main	Roslyn and Tache	Pipe badly pitted. One hole eaten through
Sept. 7/09	Domestic water main, 6″	Notre Dame, east of Ellen	Pipe 1.5+to track. Pipe 2.0+ to telephone cable; pipe eaten through; see later trouble
Oct. 20/09	Domestic water main, 4″	East side of Princess, opposite Elgin	Pipe eaten through two holes; coupling badly pitted
Dec. 11/09	Domestic water main, 4″	South side William, corner Adelaide	Two holes eaten in pipe; coupling badly pitted
Dec. 24/09	Domestic water main, 8″	East side Main, north of Portage avenue, east	One hole 1½″ long
Feb. 25/10	Domestic water main, 4″	East side Princess, opposite Elgin	Pipe broke in two and badly pitted
Sept. 22/10	Domestic water main, 6″	Fort street, near York	
Nov. 21/10	Domestic water main, 6″	South side Ellice, near Hargrave	Two holes 7″ long eaten through
Feb. 1/11	Domestic water main, 4″	Portage, 20 feet west of Smith	
May 10/11	Domestic water main	Ellice and Donald	
Aug. 19/12	Service Pipe	Argyle street	Special reference see Page 6, City's case
Aug. 19/12	Service pipe	Garry near Assiniboine	
Jan. 3/13	Domestic water main, 4″	Stanley street, 30 feet, North of Alexander	Pipe eaten through
Jan. 13/13	Lead service pipe	No. 326 Ross avenue	Pipe eaten through and badly pitted
Jan. 18/13	Domestic water main, 8″	Broadway and Edmonton	Pipe eaten through bottom side
Sept. 25/13	Domestic water main, 4″	Stanley street, 65 feet, N. of Alexander	Two holes eaten through pipe (second trouble near this point)
eb. 14/14	Domestic water main, 4″	June, north of McDermot avenue	Pipe eaten through
Mar. 30/14	Domestic water main, 4″	Vulcan Iron Works, Maple and C.P.R. tracks North	Pipe .3 to .4+ to spur track; Main badly pitted; one hole; corporation cock blown out; current on C.P.R. track from Gas Works spur towards Main street
Apr. 1/14	Domestic water main, 4″	Ellen 160 feet, N. of Notre Dame avenue	Water main slightly + to gas; pipe eaten through; about 20 holes; see damage on 27-9-09

The city submits that the following, among other remedies, are necessary in the premises for the protection of the various underground structures against stray electric railway currents:—

1. That an adequate system of insulated negative return feeders, so proportioned and arranged as to efficiently protect all underground metallic work from electrolytic damage, be installed by the Winnipeg Electric Railway Company.

2. That a standard be prescribed wherein the maximum difference of potential between any two points on the return circuits of the Winnipeg Electric Railway system 1,000 feet apart shall not exceed the limit of 0.3 volt during the average schedule traffic and that the maximum over-all voltage drop within the city limits shall not exceed the limit of over 7 volts.

3. That insulated pilot wire circuits and recording voltmeters be installed at each street railway substation so that accurate chart records may be obtained daily showing the difference of potential between negative busbars in each substation and at least four extreme limits on the return circuit in its corresponding feeding district and that such instruments and chart records be open to the inspection by the city at all reasonable hours.

4. That a standard be set for the maximum allowable limits of stray currents in foreign underground structures.

5. That owing to the fact that the water-mains of the City of Winnipeg are being extended into the municipalities of Kildonan on both sides of the Red River and that the City of Winnipeg water mains are now and have been for some time metallically connected with the water-mains of the City of St. Boniface and further that the street railway tracks in St. Boniface and Kildonan are a part of the system operating in Winnipeg, that the Commission determine what steps are necessary to prevent stray currents from being diverted to the City of Winnipeg's water-mains from the tracks of the company in districts outside of the corporate limits of the City of Winnipeg.

6. That a standard set of requirements covering safety to underground structures be formulated and applied to the operations of all interurban electric railway lines outside the corporate limits of the City of Winnipeg, but adjacent thereto, whereby the city's water-pipe lines, or pipe lines of other interests connected thereto or that may hereafter be connected thereto may be protected, particularly the following:—

(*a*) The present steel 36in. water-pipe line running between the various wells of the city to the north and to the city's main pumping station and to the main reservoir at McPhillips and Logan;

(*b*) The proposed steel pipe line of the Greater Winnipeg Water District, extending from Transcona through St. Boniface and to McPhillips and Logan;

(*c*) That such requirements as soon as formulated be applied, particularly to the electric railway systems proposed to be constructed between the town of Transcona and Winnipeg.

7. That the operation of each street railway substation be continuous during the schedule hours of operation of cars, unless in the case of unavoidable accident, and that in all cases of shut-down through accident the city electrician be notified thereof.

8. That a direction be made as to the tying in of the various substations to each other, so that the readings specified in clauses two and three hereof be not rendered misleading.

9. That, if any system of current drainage is prescribed for the ultimate protection of lead sheath cables, that directions be made as to efficient prevention of reversal of current flow in the same.

10. That at the east end of the Bannerman avenue track there should be a direct connection between such track and the rails of the Main street system instead of via an overhead negative running back to Main and Anderson, approximately 1,250 feet farther away from the substation supplying the Bannerman avenue line.

11. That, in cases similar to those existing on Notre Dame avenue west, that the provision of suitable overhead negative returns running by the most direct route to the nearest substation would form a path of lower resistance than exists at present by the tracks.

12. That a direction be given as to a standard of insulation of all underground negative street railway feeders and that all underground negative street railway feeders now existing or hereafter installed be made to comply therewith.

June 15, 1914.

LETTER FILED BY CITY OF WINNIPEG RELATING TO GAS LEAKAGE.

24th June, 1914.

Dear Sir,—I have been instructed that, when the ground is opened in the vicinity of the gas mains, there seems to be a tremendous escape of gas. It is possible that this is due to electrolytic action in connection with these mains? It may be that so long as the mains are thoroughly coated with Winnipeg clay they do not break down, but as soon as the clay is disturbed (for instance by an accidental flooding of water or

removal of a support for other underground work) then this odor of gas is most pronounced.

I am also instructed that this gas is now in a number of the conduit systems, including the Government telephone system, and if such is the case there is danger of a serious explosion some day.

Yours truly,

THEO. A. HUNT,
City Solicitor.

BRIEF FILED BY MANITOBA GOVERNMENT TELEPHONE COMMISSION.

MANITOBA GOVERNMENT TELEPHONES.

Office of the Commissioner.

WINNIPEG, Man., June 12, 1914.

JUDGE ROBSON,
Public Utilities Commissioner, City.

Dear Sir,—Acknowledging your communication of June 10th, I beg to submit a review of the damage by electrolysis as applicable to telephone cables in Winnipeg.

The term "electrolysis" has been applied to the action of stray electric currents on the lead sheathing of telephone cables. The action is such that whenever electric current, having taken circuit by route of the telephone cable sheathing, at the point where it leaves the cable to accept a more conductive path to return to the power station, it will disintegrate the lead sheathing, turning the lead into red lead. The degree with which the cable will be eaten up depends largely upon the amount of moisture at that point. Experience has proven that when the stray electric currents from the street railway system are picked up by the telephone cable that no harm occurs to the cable at this point. Telephone engineers have therefore overcome to a large extent the damage caused to telephone cables by electric street railway currents, by running a heavy copper wire from the return end of the telephone cables back to the power station, thus preventing the electric current from leaving the cable, after it has once accepted the cable as a path of its circuit. In the earlier years of this experience, engineers thought it advisable to connect all telephone cables together, and further connect them by means of copper wire with the rails of the street railway system. The above methods are, however, not good practice. It will be seen that if the above practice is carried out, that the amount of current

which may be passing over the telephone cables in bulk, in a large city, may easily amount to several hundred amperes. This large amount of current being picked up along the entire route must pass from the rails of the street railway system to the telephone cables, which in many cases are some twenty feet (20″) distant, and thus all water pipes and gas pipes which lie within the space above mentioned will be subjected to the full force of the electric current, and probably become completely disintegrated in the course of time.

In latter years, therefore, telephone engineers have abandoned these practices, not so much for their own interests, but in regard to consideration for the gas companies and the water companies, and have insisted that the street railway system shall not only bond its rails, but shall supply as many copper feeder circuits as are necessary to return all current back to the busbar of the machine at the power station, instead of allowing their currents to take circuit through the earth, water pipes, gas pipes, telephone cables, etc.

A great deal may be done by the street railway company through thoroughly bonding their rails, one to the other. This, of itself, however, would not alone take care of the matter, as, in a large city the size of Winnipeg, the amount of current the street railway company used on its cars could not be possibly carried back to the station over the rails as a conductor only. The proper method for the street railway company to adopt, in the laying out of their overhead distribution system, is such that their return feeders to the power stations balance, in weight of copper, the feeders that they now have carrying to the trolley wire and feeding it at various points. Such return feeders should be connected to the rails at the various points indicated.

All telephone cables, water pipes, gas pipes and other electric conductors should never be connected to any portion of the street railway system, and even where possible it is advisable to enhance the insulation of such cables from the ground. It is questionable whether all telephone cables should be bonded together in the manholes, and, if telephone companies could depend on the street railway company to carry out the above mentioned method, it would probably be advantageous to the gas and water companies for the telephone cables to be disconnected from each other in the manholes; in this way reducing the total volume of the current passing transversely across the streets.

REVIEW OF WINNIPEG SPECIAL CONDITIONS.

Telephone cables were first laid in Winnipeg, underground, in the year 1899, being laid from No. 366 Main street to the building on the south side of Thistle street, which is now known as Portage avenue east. In the following years these cables were extended to the corner of Broadway and Main street and to a point on Fort street, at its intersection with Broadway. Almost as soon as these cables were laid it was noticed that electrolytic action was taking place along the cable whenever the manhole became filled with water. A heavy copper wire

was then laid from a point on Fort street and Broadway to the power station on Assiniboine street. In the years 1901 and 1902 this particular wire, and the cables attached thereto, were carrying a current of 150 amperes, as actually measured, the difference of potential between the cables and the ground at this point averaging four to six volts.

At any point on Main street, between Broadway and Main and Market and Main, the difference of potential during these years, and continuing up to the year 1905, averaged from four to six, and sometimes seven volts difference of potential at the Market street manhole. The difference of potential naturally varied with the number of cars running and the position of the cars on the street. The telephone cable was of the negative sign, but whenever the manhole at the corner of Broadway and Main street filled with water, any piece of cable which did not happen to be connected to the others would be positively eaten up within twenty-four hours, and in the year 1905 a piece of 300-pair cable was laid from this manhole to the Fort street manhole on Broadway. Before the cable could be spliced up and its lead sheathing connected and bonded in the spring of the year, the thawing of the snow and ice caused water to flood the manholes, and this section of cable which was brand new, and had never as yet been in use, was entirely disintegrated, and it had to be removed. In the same year the 400-pair cable in the Broadway and Main street manhole was eaten into, and a section some three feet long had to be cut out and replaced, great inconvenience being caused to the Fort Rouge subscribers while this was being done.

In the latter part of 1905 and 1906, tests for electrolysis were being constantly made, and it developed that electrolytic action was taking place in the manhole on Thistle street, which is now known as Portage avenue east, just opposite the Rorie street lane. A heavy copper wire was therefore run down the street railway company's pole at this point, and connected to the telephone cables, all of which were then carefully bonded together. This wire was a heavy copper wire, probably as large in size as a man's thumb, and the wire as it went up the pole from the manhole, was at all times hot, due to the amount of current which it was carrying, deflected from the telephone cable. On an ordinary day, a person passing down the street could put his hands against the wire, and it would be distinctly hot although, of course, it was not red hot or dangerous. We had at this time no ampere meter in our possession, and neither did the city electrician, which could measure the amount of current passing along this wire. It could not, however, have been less than approximately 300 amperes.

About this time it was a common occurrence to see the electric current arcing between the sections of rails at the corner of Notre Dame and Portage avenue, just opposite the lane between Ellice and Portage avenue. During the years 1901 to 1907, the attention of the management of the street railway company was constantly called to the lack of proper methods, and even to the lack of supervision in regard

to such methods as were established, and also to the constant damage that was being caused at different points to telephone cables generally.

During the years 1907 to 1911 the changes that took place in the power development of Winnipeg changed conditions a good deal. The power station at Assiniboine street was abandoned except for emergency, and substations were opened up at different points within the city, thus creating a distribution of the street railway currents escaping from the rails, which created a different order of things altogether. By this time the number of telephone cables had so increased, and the fact that they were all so carefully bonded together at each manhole, and also bonded to such returned feeders as had been possible, the difference of potential between those cables and the ground was naturally a little less for the amount of current that must have been flowing on them, but it still remained nearly equal to the original difference of potentials as in the early years. The minimum difference of potential between telephone cables and the rails at the present time will average three (3) volts, negative sign. Occasionally, however, a change in the distribution of the street railway current supply, such as a shutting down of a substation, affects the direction of current from the ground and therefore affects current on the telephone cables. This, however, has been so elusive that it has been impossible to make complete tests under all conditions, but there is no doubt that if something further is not done now, the telephone cables will suffer at a point on Main street, approximately near Cathedral avenue, and at a point on Pembina street, approximately near Kylemore, and further at a point on Portage avenue, approximately near Stradacona street.

The manager of the street railway company was notified on July 15th, 1913, as to the dangerous existing condition at the above points. In reply to this communication the street railway company stated that they were endeavoring to keep careful inspection of their track returns, and that they were not aware of any place where there was any escapage of current. They, however, pointed out that they knew the condition of their track at one of these points was bad, and it was promised to remedy it. They further said that they did not wish to have their current escaping from the rails, but nothing further has been done in order to remedy the matter.

It is our opinion that the street railway company should be compelled to carry all of the current which they produce, back to their power station on their own copper conductors, and that nothing short of this will ever be satisfactory to the water, gas and telephone interests. In order to find out whether they are or are not carrying such current back to their station, an expert should decide the permissible difference of potential between the telephone cables and the ground, and the minimum amperage that any telephone cable sheath of given size should be permitted to carry. So far as water pipes are concerned, the same applies to them, but the telephone cables are much easier gotten at, and if it is known what current they are carrying, it is of course certain

that the water pipes must be carrying comparative quantities of electric current.

The economic waste resultant from the loss of current produced at the street railway power house and lost due to a lack of adequate feeders, computed over a twenty year period, and capitalized, would alone compensate for the additional construction expense of a well balanced distributing feeder system including return conductors. The economic waste of the Winnipeg system, so capitalized, is in the neighborhood of five million dollars.

A map of the telephone cables, underground, in the City of Winnipeg, has been presented herewith, and a detail of the dates of letters and correspondence on the subject of electrolysis from the Manitoba Government Telephones to the city electrician and the manager of the street railway company, and a detailed list of points at which telephone cables have been damaged due to electrolysis, caused by stray currents from the street railway company's distributing system.

Trusting the information herein contained may be of assistance.

Yours respectfully,

H. E. Brockwell,
Chief Engineer.

RE ELECTROLYSIS

Date		Subject
Jan. 25/13	..To F. A. Cambridge.....	Electrolysis taking place in M.G.T. cable on Pembina avenue
Jan. 25/13	..To. W. Phillips..........	Trouble in cable sheath from manhole at Arnold and Pembina
Apr. 4/13	..To W. Phillips..........	Re destruction of our cables by electrolysis
Apr. 7/13	..F. A. Cambridge........	Discussing electrolysis (map in connection with damage to cables being prepared)
Apr. 7/13	..W. Phillips.............	Discussing electrolysis
July 15/13	..To W. Phillips..........	Electrolysis reported at Cathedral and Main, Stadacona and Portage, Pembina and Kylemore
July 15/13	..To F. A. Cambridge.....	Discussing electrolysis
July 21/13	..To F. A. Cambridge.....	Discussing electrolysis, re restriction from city, in regard to street railway making connections between our cables and their return feeders
July 23/13	..From F. A. Cambridge...	In answer to above, and taking matter up with Prof. L. A. Herdt
Aug. 5/13	..From Prof. L. A. Herdt..	Re electrolysis
Aug. 22/13	..From F. A. Cambridge...	No objection to bonding cables to negative busbar of the substations of street railway
Aug. 25/13	..To W. Phillips..........	Re electrolysis, quoting Prof. Herdt's letter, and suggesting matter be taken up with Public Utilities Commissioner
Aug. 30/13	..From Mr. Phillips......	In answer to above
Sept. 2/13	..To Mr. Phillips.........	Referring to letter of July 15th to W. Phillips, and requesting to have the matters mentioned attended to

Oct. 30/ . . To F. A. Cambridge . . . . . Discussing electrolysis
Dec. 9/13 . . To F. A. Cambridge . . . . . Unable to get street railway to move in the matter and suggesting that it be placed before the Public Utilities Commissioner
Dec. 12/13 . . From F. A. Cambridge. . . . In answer to above and agreeing with same
May 6/14 . . To Northern Electric Co. . Re cable destroyed on Main street between College and Mountain avenue

DATES AND SPECIAL CASES OF DAMAGE TO TELEPHONE CABLES BY ELECTROLYSIS

Aug. 9/09 . . Section, manhole, Logan, east of Main; section replaced
Apr. 7/10 . . 400-pair cable, lane east of Main, north of Market; section replaced
Oct. 14/11 . . 400-pair cable, manhole, Broadway and Main, replaced
July 21/11 . . Broadway and Main manhole, section replaced
Apr. 23/12 . . 200-pair cable, Corydon and lane west of Nassau; section in manhole replaced
Aug. 1/12 . . Pole end, Raglan road, south of Portage, replaced
Feb. 24/13 . . 200-pair cable pole and section at Main street, north of Market, replaced

All of the above cases of trouble were due to electrolysis of the cable sheath.

BRIEF FILED BY WINNIPEG ELECTRIC RAILWAY CO.

WINNIPEG, June 15, 1914.

A. W. SMITH, Esq.,

Secretary, Public Utilities Commission, City.

Dear Sir,—As suggested in your favor of the 10th instant, we herewith enclose statement of a few of the facts leading up to the electrolysis inquiry to be made by Professor Ganz.

In the early stages of the construction and operation of the street railway in Winnipeg, the street conditions were very unfavorable for the construction of street railway tracks, and permanent pavements were not put down, and it was a difficult matter to have permanent roadbeds, and the street railway service was very limited and the amount of current used so small that the escaping currents did not enter into the question; however, about the year 1900 the general development of the City of Winnipeg and the country generally, made demand for increased service, and the construction of extensions of street railway tracks and the putting down of permanent street pavements, and roadbeds, was considered.

At this time the matter of taking care of the return current was taken up, it was insisted by the city electrician that negative cables be buried between the rails and bonded to the rails along at different

intervals and connected to the negative busbars at the station, which was done wherever any permanent pavement and roadbed was put down. However, this did not appear to remedy the situation, and the company went into the study of other means, and it was decided to establish a number of outlying substations owing to the development of the system and the increased amount of current flow from and to the substation, and at about 1909 the city engaged Professor Herdt, of McGill University, to make an investigation and report on recommendations for the elimination of any escaping current, and in his report he recommended practically what the company then had under way, the establishment of the outlying substations and that the voltage drop in the tracks be kept in accordance with British Board of Trade rules. He also condemned the underground negative cables buried between the rails, and the company, to carry out his recommendations in this matter, erected a number of aerial negative cables. The voltage drop in the track is being carefully watched all the time by bond testing instrument and test wires which run out along the main track from each substation, and the results which we have had from these tests would indicate that the drop in track is well within the British Board of Trade rules. We have records of all tests made which are open to the inspection of Professor Ganz. We have a peak load of 16,000 amperes and an average load of 10,000 amperes delivered from six substations as follows:

Main substation, or No. 1, peak of 5900, average 3800;
No. 2, peak of 1400, average 1100;
No. 3, peak of 3500, average 1500;
No. 4, peak of 1800, average 1000;
No. 8, peak of 1500, average 1000;
No. 10, peak of 2000, average 1600;

so that it will be seen that the load has a good distribution and there is not any large quantities centered in any one station.

The way we take care of this return current is fully shown in the plans and drawings which we submitted, just where each cable runs is all shown on these plans, also plans showing the bonding of all street special work, street intersections, etc., which has all been done in accordance with the recommendations of Professor Herdt.

In the past when the city electrician or any city official has notified us that he has found any objectionable condition in connection with our return current, we have immediately taken steps to find if such is the case, and if so, the necessary remedy was always provided. Some years ago the city electrician and city authorities insisted that no other system of bonding be used except the brazed bonds, which from experience we have found to be very difficult and expensive one to maintain. Some parts of the system which were bonded with other types of bonds have been found to show equally as well or better tests and no troubles or annoyances with renewals due to broken bonds, and

we believe had this company been allowed to use its own discretion in the matter of bonding, very much expense could have been saved and very much of the trouble and annoyance from defective bonding would have been eliminated, but we were under the direction of the city electrician, and he refused to approve of any other system except the brazed bonds.

We have submitted to you, through Mr. Skinner, a plan of underground cables, wires, gas mains, as well as all track work, and everything that has been asked for, as we understand it, by Professor Ganz. We have nothing to conceal, and are open to a free discussion, and an investigation in connection with the matter, and will be glad to give Professor Ganz any additional information and assist him in any investigation which he may desire, and will be very glad to discuss the matter with him in every particular, for it is our desire and very much in the interests of the company to have the system in the best shape possible, and to eliminate any conditions which would cause destructive escaping currents.

I may add that we have here in the city a very large system of gas mains, and so far, have never found any damage to the mains by electrolysis, and we would suppose that if there was any extensive damage to underground structures, it would naturally show a certain amount on the gas mains, and generally we are of the opinion that our railway system is at present in such condition that there is no serious damage due to stray railway currents.

We have before us a letter from Professor Ganz, dated April 20, 1914, written to the editors of the Electric Railway Journal and published in their paper of April 25, 1914, in respect to electrolysis mitigation, and, after reading this letter, I find that our system of negative returns and checking up of the drop in the rails has been practically along the lines as laid down by Professor Ganz in this letter.

I find it difficult to take up all the points in connection with this that may have occurred during the last 12 or 14 years without first knowing what arguments the city is going to make to show that our system is not in first class condition, but after we are informed as to what this will be, we will be pleased to answer any of the criticisms made by them.

Yours truly,

W. Phillips,

Manager.

SECTION II.

SUMMARY OF REPORT AND RECOMMENDATIONS RELATING TO THE CITY OF WINNIPEG.

Review of electrolysis conditions in Winnipeg.—The only source of stray currents which may seriously affect underground structures in Winnipeg is that part of the railway system of the Winnipeg Electric Railway Company which receives direct current from power or substations located within or close to the city limits of Winnipeg.

From 1890 until 1906 the entire electric railway system of Winnipeg, which was then a relatively small system, was supplied with direct current from a steam generating station located on Assiniboine avenue, at Garry street. During this period stray currents from the railway system concentrated towards this station, making this region the electrolysis danger zone; and early reports show that these stray currents caused very considerable destruction of underground structures by electrolysis in this neighborhood, particularly on Broadway and on Main street, near the river. In 1906 substation No. 1 in Mill street at the Red River was placed in operation. This substation received high-voltage power from a distant hydro-electric plant, and from a steam-driven plant located in the same building. This substation became the principal source of direct current for the electric railways in Winnipeg, and the old steam generating station on Assiniboine avenue was retained only as a reserve. Stray currents from the electric railways then concentrated near the corner of Portage avenue and Main street, where the tracks were connected to negative return feeders from substation No. 1, and this became the center of a new electrolysis danger zone. Considerable trouble from electrolysis soon developed in this neighborhood, and conditions here became so serious that in 1909 the city engaged Professor L. A. Herdt to report on the electrolysis conditions and to recommend remedial measures.

Professor Herdt recommended in substance the following: that distributed substations be installed at different points in the city in order to relieve the concentration of current towards Portage avenue at Main street; that the rail joints, tracks and special work be properly bonded; that track return feeders be installed; that the track voltage drop be kept within the British Board of Trade regulations; that the return feeders from the corner of Portage avenue and Main street to substation No. 1 be carried in underground conduits and be increased in size to at least 10,000,000 circular mils; and that a system of track return inspection be adopted by the railway company.

The Winnipeg Electric Railway Company had, at this time, already in contemplation the addition of distributed substations to take care of the rapidly increasing load, and during 1909 put into operation

substation No. 2 on Osborne street at Kylemore avenue, substation No. 3 on Portage avenue, at St. James street, and substation No. 4 near Main street, at Inkster avenue. During 1912 substation No. 8 on Logan avenue, at McPhillips street, and substation No. 10, on Assiniboine avenue, at Garry street, in the building with the old steam generating plant, were put into operation. The addition of these substations was practically made necessary by the great extension of the electric railway system and the increase in traffic. This increase in traffic has been particularly heavy in the center of the city, which is supplied from substation No. 1; so there continued to be considerable concentration of current towards the corner of Portage avenue and Main street, notwithstanding the operation of the five added substations. *To relieve this and also to afford much more satisfactory electrolysis conditions it would be very desirable to add a substation near the corner of Sherbrooke street and Portage avenue, where there is great concentration of railway load.*

Judging from the rail bonding records obtained by the railway company and from the results of measured and computed track voltage drops, and also from such tests and inspections of tracks as I have made, I am of the opinion that the bonding of the tracks and special work in Winnipeg is now in generally satisfactory condition.

Track return feeders have been installed on Main street, north and south of Portage avenue, across several of the bridges, and near substations No. 3 and No. 10, but these parallel the tracks and have but little effect in reducing stray currents through earth.

The British Board of Trade regulations require that the over-all track voltage drop be maintained within the limits of 7 volts. This is not done in Winnipeg, as over-all track voltage drops of from 10 to over 20 volts were found.

The return feeders from the corner of Portage avenue and Main street to the negative busbar in substation No. 1 have been placed in underground conduits and have been increased to a total cross-section of 14,500,000 circular mils. This increase in cross-section of these feeders has, however, not reduced the danger from electrolysis in the center of the city, because no matter what the cross-section of these feeders may be, the tracks at this corner must with the present return feeder layout be the point of lowest track potential for this substation district.

A potential wire has been installed from the tracks at the corner of Portage avenue and Main street to the negative busbar of substation No. 1, with a recording voltmeter in circuit, and continuous records of the voltage drop in this feeder have been kept. This voltage drop is, however, of no significance so far as the protection of the underground structures in the center of the city is concerned. Potential wires have also been installed along several track lines, but no measurements or records of over-all track voltage drop have been periodically or regularly made.

Since the distributed substations have been in operation, trouble from electrolysis has continued to develop in the center of the city, but to a very much less extent than formerly, probably due to the improvement in track work. At each of the new substations the tracks are directly connected to the negative busbar, and as a result the tracks directly at each substation are at a lower potential than any other point in that district. Electrolysis danger zones have, therefore, been created around each of the substations, and a number of cases of destruction of underground pipes and cables by electrolysis have already developed in these regions. On this account many tests, consisting principally of measurements of potentials of underground structures referred to trolley tracks, have been made by the city electrical department and by the Manitoba Government Telephone Commission, since these troubles were first noticed. During the early spring of 1914, prior to the beginning of my investigation, potential surveys of underground pipes and cable sheaths were made by the city electrical department and by the Manitoba Government Telephone Commission. The results of these tests have been furnished me, and a study of them indicates that a high positive potential zone has been created in the neighborhood of each of the railway substations.

The Winnipeg Electric Railway Company has power cables in underground conduits running from substation No. 1 to substation No. 3 along Portage avenue. In order to protect these cable sheaths against destruction by electrolysis, the railway company had installed electrical drainage connections from them to the return feeders of substation No. 1 directly in front of the substation and at the corner of Portage avenue and Main street, and to the negative busbar of substation No. 3. The Manitoba Government Telephone Commission had also installed an electrical drainage connection from the telephone cable sheaths to the railway return feeder cables in Portage avenue east, at the Main telephone exchange, in order to protect the telephone cables from electrolysis. A 2-inch Pintsch gas pipe running alongside of the transfer railway was also electrically drained at Lombard street to substation No. 1 in order to protect it from electrolysis. Tests which I have made showed that the total current drained from the cable sheaths and this gas pipe to the return circuit of substation No. 1 was about 14 per cent of the station current.

The installation of the electrical drainage connections from the cable sheaths and the Pintsch gas pipe directly at substation No. 1 were made because of the tendency for current to leave these structures for earth in the immediate neighborhood of this substation. A fire and police telegraph cable together with the iron conduit in which it was carried, leading into the substation, had in fact been twice destroyed by electrolysis. This tendency for current to leave underground structures directly at substation No. 1, which is about 1,200 feet from the nearest electric railway tracks, was found to be due to the fact that the negative busbar in substation No. 1 was grounded through contacts between the negative cables and the iron conduits in which they were drawn, and between these conduits and the gas and water piping of the station.

Since this grounding of the negative busbar constituted a serious and wholly unnecessary source of danger to underground structures in the neighborhood of Mill street, it was eliminated at my request during the summer of 1914, and the negative busbar in substation No. 1 is now substantially insulated from ground at the station. With this negative bus ground connection removed, the danger to the underground structures in this neighborhood has also been eliminated, and the electrical drainage connections in Mill street from the Pintsch gas pipe and the railway cable sheaths have become unnecessary and have therefore been removed.

As stated before, danger districts have been established in the neighborhood of each of the ne wsubstations, and some destruction of underground pipes and cables has already occurred. More actual trouble has not been experienced so far probably because most of the underground cables were laid only a few years ago, and the substations have been in operation only for a relatively few years. It is evident, however, that all underground structures in the neighborhood of each substation are in serious danger of destruction by electrolysis. This condition was found to be particularly acute in the case of the underground cable sheaths of the Manitoba Government Telephone Commission, of the city light and power department, and of the city fire and police telegraph department. This situation appeared so serious that I did not believe it safe to allow these cables to remain in the condition found for any considerable time, and I did not think it wise to allow protection for these cables to wait until adequate railway improvements could be finally made. With the approval of your Commission, I, therefore, had installed temporary electrical drainage connections from these cable sheaths to the railway return conductors in each of the substation districts. The results of the detailed investigation on the cable sheaths to determine both their electrical condition and where the temporary drainage connections should be installed, have already been submitted to your Commission in a preliminary report dated November 17th, 1914, given as an Appendix to this report. It was not possible to apply any satisfactory and safe remedial measures to the water piping systems to protect them against their present danger from electrolysis.

Tests made Under the Writer's Direction.—Current measurements on the high- and low-pressure water piping of Winnipeg were made at characteristic points in each substation district whenever the mains were accessible or were exposed for these tests. At nearly all points where such tests were made, substantial stray currents were found flowing toward the substation supplying that region, and 24-hour records of these currents obtained at a number of points showed characteristics which agreed exactly with the characteristics of the track voltage drop in that particular region. This is conclusive proof that the currents found were straying from the tracks of the electric railways.

Potential measurements of the water pipes referred to trolley tracks showed that in the vicinity of the substations these were generally highly positive to these tracks, and at points distant from the substations they

were generally negative to the tracks. The values found were substantially in accord with those reported by the city electrical department. In every substation district the positive pipe potential referred to the tracks at the station, and the negative pipe potential referred to the tracks at the feeding limit of one track line, were also obtained, simultaneously with the voltage drop in this length of track. From these simultaneous measurements the drop in this section of the water piping system was computed. These voltage drops were found to be relatively high, indicating that the underground water piping carries substantial stray currents from the electric railway system.

The water pipes were exposed for current measurements in neutral and negative districts, where currents were likely to be the largest, but where the pipes were not thought to be corroded by electrolysis, except in special cases. It was found that in every case where the electrical conditions at present and as far as known in the past were such that electrolysis could not have taken place, the cast-iron mains were in good condition and did not show any graphitic pitting which is generally characteristic of electrolysis, thus indicating that the Winnipeg soil does not of itself produce this result. Where stray currents leave the iron and flow to soil this graphitic action is however produced.

A number of cases of corrosion of pipes and cables by electrolysis came to my notice while I was in Winnipeg. A break which occurred in a 4-inch water main in St. James street, near substation No. 3, directly caused by the falling away of soil under the main due to sewer construction, showed that the main in this region was very seriously corroded and pitted by electrolysis from stray currents returning to this substation. Three lengths of pipe were in such bad condition due to electrolytic corrosion that they had to be replaced. At substation No. 2, on Osborne street at Kylemore avenue, a lead service pipe leading into this substation was destroyed by electrolysis and was renewed while I was in Winnipeg. The water main on the east side of Osborne street at Morley Avenue which was exposed when replacing a destroyed service pipe, also showed deep graphitic pitting caused by electrolysis. The water mains which were exposed in Portage avenue at Main street, at Fort street, and at Hargrave street, also showed serious electrolytic pitting. Numerous service pipes have also been destroyed by electrolysis during the past year. The Manitoba Government Telephone cable in the manhole on Osborne street at Arnold avenue was also found seriously corroded and pitted by electrolysis. In view of these cases it did not seem desirable to search for other pipes and cables corroded by electrolysis for this would be impossible without going to very large expense and without damaging the pavement. The current and the potential measurements made on the cable and water piping systems together with the corrosion from electrolysis which has already been found, afford sufficient evidence that electrolysis from stray currents is going on in the vicinity of each of the rail substations.

A rather striking example of stray currents leaving pipes is found in McDermot and Alexander avenues at Arlington street, where

currents averaging about 10 amperes are found flowing towards McPhillips street on each of the high-pressure water mains. Since this high-pressure piping does not connect metallically to any other piping west of Arlington street this current must be leaving the high-pressure water mains in McDermot and Alexander avenues, west of Arlington street, and in McPhillips street, and be producing corresponding corrosion by electrolysis.

Over-all track voltage drop tests were made in the course of the present investigation in every substation district, and the average value of this drop for the peak-load hour and the highest average for ten minutes during the peak-load hour were obtained. It was found that these over-all track voltage drops reach average values of from 10 to over 20 volts for ten consecutive minutes during peak-load hour. A number of 24-hour records of over-all track voltage drop were also obtained together with the current output and current distribution from each railway substation. From these data, from estimated resistance for the track circuit, and from the car schedule during peak load, the average over-all track voltage drops in each of the substation districts were computed for the ten minutes of highest load. It was found that the computed values of over-all track voltage drop were in nearly all cases considerably higher than the measured values, in many cases being nearly twice the measured values. The computation of track voltage drops were made on the assumption that all of the current returned by the tracks and negative feeders, and that none leaks to earth. Where these measured values are much smaller than the computed values this is, therefore, an indication that a considerable part of the current leaks from the tracks and flows through earth and through the metallic structures buried in earth. The fact that the measured track voltage drops are generally smaller than the computed values is also an indication that the rail bonds and special work bonding are generally in good condition, which is confirmed by the low values of voltage across rail joints and special work obtained in a large number of scattered tests.

A few tests of potential gradient in the tracks were also made in the neighborhood of substations No. 1 and No. 3, and these showed relatively high values. This is due to the great concentration of return current in the tracks near these substations.

General Discussion of Remedial Measures.—Complete prevention of stray currents from electric railway cannot be obtained with the single-trolley system, but can be attained only by employing some railway construction like a double-trolley system which completely insulates the electric railway circuits from earth. Stray currents from a single-trolley railway can, however, be reduced to any desired low values by correspondingly extending the application of distributed substations and insulated track return feeders, *the limit being controlled solely by the cost of installation and maintenance.* It is my opinion that stray currents through earth from the present electric railway system in Winnipeg can be so reduced, by maintaining the entire track network

as a conductor of the lowest possible resistance and by reducing the track voltage drop, that the underground piping systems are substantially free from injury by electrolysis. A few special cases may arise where additional measures such as insulating covering or insulating joints may be desirable. As to the lead sheaths of the underground cables, which are many times more susceptible to injury by electrolysis than are iron pipes, it is not possible to predict whether these cable sheaths will be sufficiently protected by such railway alterations and extensions as will reduce the track voltage drop to the limits recommended below. It is possible that a limited amount of electrical drainage for the complete and final protection of these cables will be required. However, such limited cable drainage, if properly applied and controlled, is not objectionable and will not cause appreciable danger to other underground structures.

The British Board of Trade regulations have been in effect in Great Britain for about twenty years, and practically no cases of destruction of underground structures from electrolysis have been reported there. The 7-volt over-all track voltage rule of the British Board of Trade, together with the requirements of potential wires for measuring track voltage drop and of periodic recording of these voltage drops, seem from long experience to be the features of the Board of Trade Regulations which have made them successful. These requirements, together with a track voltage limitation of 1 volt in 1,000 feet of track, have also been included in several municipal electrolysis ordinances in the United States. The limit of 1 volt in 1,000 feet of track is necessary in order to avoid concentration of current through earth and underground structures. For these reasons, which are also more fully explained in section III, I have included these requirements in the recommendations for Winnipeg which follow, as the best practice both in Great Britain and in America. The other requirements included in the recommendations also follow what is considered the best practice both here and abroad. *All of the recommendations relating to the electric railways can be carried out in the electric railway system of Winnipeg without involving an expense larger than the present conditions warrant.* Attention should, however, be called to the fact that the British railways actually operate well below the prescribed 7-volt limit; *so a compliance with the 7-volt rule will not necessarily insure the same degree of immunity as is enjoyed in Great Britain.* Where, therefore, still lower track voltage drops can be secured at a reasonable cost, such lower voltages are desirable.

In the extension of or in the laying of new underground piping systems, every precaution should be taken to increase as much as practicable the resistance between the electric railway tracks and the pipes. To this end the pipes should be laid as far away from electric railway tracks as practicable, and where possible the crossing of pipes, particularly of service pipes, under electric railway tracks should be avoided. In certain special cases insulating joints in the pipes may be used, where these will materially increase the resistance of the paths of stray currents to or from the pipes, provided their location is such that

they do not cause an excessive potential gradient to be set up around the joint. Where a service pipe from a main is laid crossing under electric railway tracks to which the pipe is positive in potential, it is sometimes desirable to install an insulating joint in the service pipe close to the main; or where preferred to surround the service pipe by a sufficiently thick layer of insulating material. There are many available forms of insulating joints for pipes, and such joints are relatively inexpensive to install when new pipes are laid. Where there are flanged joints, these can readily be made insulating with but little added expense, by providing a disk of insulating material between the faces of the flanges, and by suitably insulating the bolts, bolt heads and nuts. It is undesirable to employ a single insulating joint buried in earth in a long pipe line, and generally several successive joints of such a pipe line should be made insulating in order to afford longer and better distributed leakage paths around the joints.

Recommendations.—In order that stray currents in Winnipeg may be reduced to such low values as will afford a reasonable degree of protection to underground structures against destruction by electrolysis, and as will prevent flow of stray currents on underground structures of such magnitudes as to constitute a fire hazard to buildings, I beg to offer the recommendations given in the following paragraphs. The recommendations relating to improvements to be made in the railway system apply to that part of the system which is supplied with direct current from stations located within or near the city limits of Winnipeg, except where otherwise stated. I wish to point out that in these recommendations relating to improvements in the railway system, I have avoided as far as possible specifying types of construction, and have generally recommended the results to be attained, leaving the decision of the mode of obtaining these results to the railway company.

Recommendation No. 1.—Every rail joint in the tracks of the electric railway system shall be so constructed and maintained that its resistance does not exceed the resistance of eight (8) feet of continuous rail. Tests of the resistances of rail joints shall be made and recorded at least once every year, and when defective joints are found they shall be promptly repaired. (This requirement of rail-joint resistance is purposely made liberal but is considered adequate when the track voltage drop requirements recommended below are carried out.)

Recommendation No. 2.—The two rails of every single track and the four rails of every double track shall be maintained adequately cross-bonded, and all special track work shall be spanned by copper wire jumpers of adequate current-carrying capacity. (The present practice of the Winnipeg Electric Railway Company in regard to cross-bonding and special-work jumpers, as shown in their drawings of track construction, is satisfactory, and for this reason it is not deemed necessary to make a more definite requirement in regard to this.)

Recommendation No. 3.—All conductors which connect the tracks of the electric railways to the direct-current supply stations shall be

insulated from earth. (It is not necessary to specify the kind of insulation required for these conductors. Where laid in underground ducts, rubber, paper, or similar insulation with lead protective covering should be used, but in special cases where the ducts are dry most of the time, weatherproof insulation with double or triple braiding without lead covering may be found adequate. For overhead lines either bare or covered conductors may be used supported on suitable insulators.)

Recommendation No. 4.—No metallic connections shall be permitted between water, gas or other underground pipes and any part of the electric circuit of the electric railway.

Recommendation No. 5.—The rails or other metallic conductors forming parts of current carrying electric circuits of the electric railway which are not insulated from earth, shall be designed, constructed, operated and maintained, so that the average potential difference during any ten (10) consecutive minutes between any two points one thousand (1000) feet or less apart on said rails or other metallic conductors will not exceed one (1) volt, and, further, so that the average potential difference during any ten (10) consecutive minutes between any two points more than one thousand (1000) feet apart on said rails or other metallic conductors within the area included by Winnipeg, St. Boniface, and Elmwood, will not exceed seven (7) volts. On account of the concentration and great importance of the underground structures in the neighborhood of the corner of Portage avenue and Main street, all feeders connecting to the tracks within a radius of 1500 feet from this corner shall be so proportioned as to maintain their connection points in the tracks at the same or slightly lower potential than the tracks at this corner during peak load. Owing to the proximity of the city water works, and of the important water mains leading to this works, to substation No. 8 on Logan avenue at McPhillips street, all feeders from this station to the tracks shall be proportioned for substantially the same voltage drop during peak load. The track voltage requirements of this recommendation are to apply only to normal operating conditions on a business day, and not to occasional abnormal conditions brought about for example by fires, storms, or holiday crowds. (With the track system, car schedules, and current distribution from the substations existing in Winnipeg in the summer of 1914 when the present investigation was made, these voltage requirements necessitate the installation of an *insulated return feeder system* in each of the railway substation districts, with the return feeders from each substation proportioned for substantially the same voltage drop under average peak-load conditions, except in the case of some of the longer feeders in which a somewhat larger drop may be desirable for the sake of economy. The theoretical locations of the track feeder connection points for such insulated return feeders to bring about the deduction of track voltage drop to the above required values may be computed from assumed track resistances and from the currents delivered to the tracks from the cars during peak load; the actual layout of such feeders must, however, allow for such practical considerations as availability of duct lines.

standard sizes of copper conductors, etc. A theoretical calculation, based on the results of the investigation described in this report, allowing for the tracks now installed across Arlington street, and assuming that the Godfrey avenue line is supplied from substation No. 3 instead of from substation No. 2, indicates that suitable track return feeders connected to the tracks at the following points in each of the substation districts will reduce the track voltage drop below the values recommended. District of substation No. 1, Portage avenue, at Sherbrooke street, at Colony street, at Donald street, at Garry street, and at Main street; William avenue, at Princess street; Main street, at Logan avenue, at Higgins avenue, and at Dufferin avenue; Euclid avenue, at May street; Higgins avenue, at May street; Tache avenue, at Provencher avenue. District of substation No. 2, Osborne street, at River Park, at Scotland avenue, and at Corydon avenue. District of substation No. 3, Portage avenue, at Arlington street, at Erin street, and at Doreen street; Godfrey avenue, at end of line. District of substation No. 4, east end of Redwood bridge; west end of Redwood bridge; Main street, at Redwood avenue, at Mountain avenue, and at Bannerman avenue. District of substation No. 8, Logan avenue, at Arlington street, at substation, and at Vine street; Notre Dame avenue, at McPhillips street. District of substation No. 10, Sherbrooke street, at Wolseley avenue; Broadway, at Sherbrooke street, at Osborne street, and at Garry street; south end of Norwood bridge; both end of Main street bridge; Osborne street, at River avenue. The suitable points of connections for track return feeders to bring about the desired reduction in track voltage drop would be altered by changes in the tracks or load or by changes in the distribution of current from the substations. It should be noted that *there is very heavy railway load in the region centering around Portage avenue and Sherbrooke street, and that an additional substation located in this neighborhood, or in Sherbrooke street between Portage avenue and the Assiniboine river, would largely reduce the amount of track return feeder copper needed to reduce the track voltage drop to the required limits. Such an additional substation would likewise reduce the feeding limits of other substations, and this would further tend to reduce stray currents.* The cross-section of the track return feeders is independent of the track voltage drop to be maintained, and is determined by economic considerations—that is, such sizes of feeders should be chosen as will make the sum of the fixed charges and the cost of the power losses a minimum.)

Recommendation No. 6.—Potential wires insulated from earth shall be installed in every substation district, whereby contact may be made to the tracks at each point where a return feeder from this station connects to the tracks, at the feeding limits of this substation on the principal track lines where these terminate within the limits of Winnipeg, St. Boniface and Elmwood, and at the points where principal track lines cross the limits, including Winnipeg, St. Boniface and Elmwood. These potential wires shall terminate in the substations in such a way that they can be conveniently connected to an indicating voltmeter and to a 24-hour recording voltmeter. One voltmeter of each

type shall be provided for each direct-current supply station, so arranged that the potential difference between any two of the above described points in the track system can be measured or automatically recorded. A potential wire shall also be connected to a nearby water pipe by means of which the potential of the negative busbar referred to earth may be measured or recorded. (Separate potential wires may be run to each selected point in the tracks at which a potential measurement is to be made, or one potential wire may be run along each track line, and be provided with suitable switch arrangements so that it can be connected at will to any one of a number of points along this track line.)

Recommendation No. 7—By means of the potential wires and voltmeters provided for in recommendation No. 6, the following measurements and records shall be obtained: The average potential difference between the tracks at a feeder connection point near the substation and each other feeder connection point, shall be determined from readings of the indicating voltmeter taken and recorded for a period of about 5 minutes during the peak-load hour once every month. From such tests the point in the tracks which is at the lowest potential shall be determined. A 24-hour record of the potential difference between each point in the tracks at the feeding limits or at the city boundary and the tracks at the point of lowest potential shall then be determined once, every month, on a normal business day. The potential difference between the negative busbar and a nearby city water pipe shall also be obtained at least once every day during peak load. If this potential difference should fall at any time to such a low value as to indicate grounding of the negative busbar, steps should be taken by the railway company to remove the ground connection. (The indicating and recording voltmeters should have such a high resistance, that the resistance of the potential wires does not substantially reduce the readings of the instruments. Otherwise suitable correction factors must be applied to the readings of the indicating and recording meters.)

Recommendation No. 8.—All records of the tests described in the foregoing recommendations, as well as the recording meter charts, shall be open to the inspection of an authorized representative of the Commission.

Recommendation No. 9.—After the foregoing recommendations have been complied with, all drainage connections from underground lead cable sheaths to the railway return circuit in Winnipeg shall be opened, and tests of the potential of these cable sheaths referred to other structures, and of current on the cable sheaths, shall be made to determine their electrolysis condition. If these cable sheaths require additional protection, a limited amount of electrical drainage may be applied, with the consent of the Commission. Such drainage connections must be installed only under the direction of an authorized representative of the Commission and must be arranged to apply equally to all of the underground cable systems, so as to avoid setting up serious potential differences between the lead sheaths of the different cable systems. They must also be so arranged and maintained as to drain off the least current

consistent with the complete protection of the cables and without setting up dangerous voltages to other underground structures. A suitable fuse, a knife switch, and a meter shall be installed in each drainage connection, and daily readings of the current drained from the cables during the peak-load hour shall be obtained and recorded. The drainage connection must be opened whenever the station is not in operation.

Recommendation No. 10.—In future constructions or reconstructions of direct-current electric railways employing the running tracks as part of the electric circuit, such track construction shall be employed, in addition to that already required by the previous recommendations, as will give the greatest practicable resistance between tracks and earth for the existing conditions. This should be done particularly where such railways cross or run close to important underground pipe or cable lines. (Where such railways operate on private right-of-way or on the side of a country road, this can generally be accomplished by using broken stone ballast and keeping the rails out of contact with ground.)

Recommendation No. 11.—Where changes or additions in the water piping systems are made, the pipes shall be laid so as to be as far removed from the electric railway tracks as practicable, and so as to avoid as far as practicable laying pipes crossing under electric railway tracks.

It should be noted that recommendations No. 1, No. 2, No. 3 and No. 4 are made to apply to the railway lines as far as these lines are supplied with direct current from the substations located within or near the limits of Winnipeg. Recommendations No. 5, No. 6 and No. 7, however, are not made to apply to the lines extending beyond the limits of Winnipeg, St. Boniface and Elmwood, because these lines are generally located on country roads where the tracks can be substantially insulated from ground, and where there are at present no underground structures which could be affected by electrolysis.

REPORT AND RECOMMENDATIONS RELATING TO GREATER WINNIPEG WATER DISTRICT AND TO MUNICIPALITIES ADJOINING WINNIPEG.

Introduction.—The Greater Winnipeg Water District contemplates the construction of a large water supply system for Winnipeg and for adjoining municipalities. No pipes or conduits have as yet been laid, but the plans for the proposed system are partially prepared. I interviewed the engineers of the Greater Winnipeg Water District and obtained from them copies of the plans which are ready and other information relating to this proposed undertaking. Most of the municipalities adjoining Winnipeg either have no water piping system or only a very limited local system, but a number of them are contemplating the installation of a system or the extension of their present system. I visited each of the municipalities and interviewed the proper representative in order to obtain information regarding any existing or proposed piping system. In future constructions or reconstructions of electric railways in any part of the Province of Manitoba, which railways employ the running tracks as part of the electric circuit, I would

suggest that the following recommendation be complied with, in order to minimize as far as practicable stray currents from such railways.

Recommendation No. 12.—In future constructions or reconstructions of direct-current electric railways employing the running tracks as part of the electric circuit, recommendations No. 1, No. 2, No. 3 and No. 4 shall be complied with, and, in addition, such track construction shall be employed as will give the greatest practicable resistance between tracks and earth for the existing conditions. If such railways operate within city limits where there is valuable underground property which may be endangered by electrolysis, the track voltage limitations, the potential wires for measuring these voltages, and the periodic tests of these voltages, as required in recommendations No. 6, No. 7 and No. 8, shall be complied with within the respective city limits.

Greater Winnipeg Water District.—The reservoir for the Greater Winnipeg Water District is to be located in the southeastern part of Transcona. It is proposed to build an 8-foot reinforced concrete conduit from the watershed to this reservoir. A conduit of this character does not have a conductance which is comparable to that of an iron or steel conduit or pipe, but which is more nearly comparable with the conductance of ordinary soil. It therefore need not be feared that this reinforced concrete conduit will carry substantial stray currents or be endangered by electrolysis. From the reservoir a 60-inch pressure main of steel, or reinforced concrete construction, is to be laid through Transcona and St. Boniface to a point on the Red River opposite Pacific avenue. A 48-inch cast-iron main with lead joints is to connect to the 60-inch main, cross under the Red River, continue up Pacific avenue to McPhillips street, and along McPhillips street to the reservoir. I obtained from the engineers of the Greater Winnipeg Water District a plan showing the proposed route of the mains from the Transcona reservoir to the McPhillips street reservoir, and also a detailed drawing showing the design of the proposed reinforced concrete trunk line conduit.

I would recommend that, where the 48-inch cast-iron main crosses under the Red River, three consecutive joints in the main on the Winnipeg side of the river crossing be made insulating. If the connecting main from St. Boniface to Transcona is built of iron or steel, so as to constitute a low-resistance electrical conductor, three joints should then also be insulated in the 48-inch main on the St. Boniface side of the river crossing. These joints will prevent stray current reaching the main under the river and therefore protect it against possible injury from electrolysis in the river crossing.

I would also recommend that permanent electrical test stations be established on the 48-inch cast-iron main in Winnipeg when this is laid, these stations to be spaced about 1,000 feet apart. If the main from the reservoir through Transcona and St. Boniface is built of iron or steel, I would also recommend that permanent electrical test stations be located on it at points about one-half mile apart. By means of these test stations it will be possible to make tests at any time to determine whether this main carries stray currents.

In the future construction railways through the territory in which iron or steel pipes or conduits of the Greater Winnipeg Water District may be located, I would recommend that recommendation No. 12 be rigidly complied with, and that every possible further effort be made to prevent as far as practicable the escape of electric currents from the tracks of these railways causing stray currents through earth which may affect the steel mains or conduits of this water system. To accomplish this, the most effective and permanent rail bonding and cross bonding should be employed; broken stone ballast should be employed for the road bed wherever practicable, so as to maintain this as dry as possible, and the rails should be kept out of contact with ground. It is particularly important that at any point where such a railway crosses an iron or steel pipe or conduit of the Greater Winnipeg Water District, broken stone ballast be employed and extra precautions be taken at the crossing and for about 500 feet on each side, to maintain as high a resistance between tracks and the pipe or conduit at the crossing as practicable.

East Kildonan.—This municipality is located east of the Red River and north of Elmwood. The water system of Elmwood is connected to and receives its water from the Winnipeg water system, and a 12-inch cast-iron main laid on Kelvin street in Elmwood extends to the boundary line of East Kildonan. A 10-inch lateral main from the 12-inch main on Kelvin street runs east on Harbison avenue, near the boundary line between Elmwood and East Kildonan.

A single-track trolley line of the Winnipeg Electric Railway Company system runs through Elmwood, on Kelvin street, and on the east side of East Kildonan road, which is an extension of Kelvin street to the northern limits of East Kildonan. Direct current for this trolley railway is supplied from substation No. 4 in Winnipeg, so that any stray currents escaping from this railway must return to this substation. The larger part of the built-up section of East Kildonan is located east of this trolley line and there are only a few scattered residences west of it.

I met Mr. J. W. Battershill, engineer of East Kildonan, and was informed that there is at present no water piping system installed there, but that water mains are soon to be laid although no detailed plans have been made. At present it is planned to obtain water from the Winnipeg system and to connect to this system through the 12-inch main on Kelvin street and the 10-inch main on Harbison avenue, at Braze street, one block east of East Kildonan road. It is expected that meters will be installed in pits or manholes at these connecting points.

In order to prevent flow of stray current between the East Kildonan and the Winnipeg water systems through the connections at the Elmwood boundary, I would recommend that insulating joints be installed in each main connecting to the Elmwood system. For this purpose either three consecutive joints in the connecting main may be insulated, or the flanged joints on each side of a meter connected in this main may be insulated.

I am informed that it is proposed to lay a water main east of the trolley tracks on East Kildonan road. Inasmuch as most of the buildings in East Kildonan are located east of this trolley line, most of the services and laterals from this main will not cross under the trolley tracks. There will be, however, some services, and possibly a few lateral mains, which will cross under the tracks to supply the section of East Kildonan located west of this road. I would recommend that in each lateral main two consecutive joints near the principal main and two consecutive joints on the opposite side of the street be insulated.

West Kildonan.—This municipality is situated north of the City of Winnipeg and west of the Red River. Main street, Winnipeg, extends north through West Kildonan, and a single-track trolley line of the Winnipeg Electric Railway system runs on the west side of Main street through West Kildonan to Selkirk. Direct current for this trolley line is supplied from substation No. 4 in Winnipeg, so that stray currents escaping from the tracks in West Kildonan must return to this substation. An 18-inch water main on McPhillips street, Winnipeg, extends through West Kildonan to the Winnipeg water supply wells located north of West Kildonan. A new 36-inch steel transmission main is being laid on McPhillips street to replace this 18-inch main, which will be used as a distributing water main when the 36-inch main is completed.

I met Mr. F. E. Eatwell, engineer of West Kildonan, and learned from him that at present there is no water piping system in West Kildonan, but that it is contemplated to lay about three miles of cast-iron water mains with the necessary services, although no detailed plan of the layout was available. It is proposed to lay a 12-inch distributing main on the east side of Main street north from the Winnipeg City limits for about one mile, which is on the opposite side of the street from the electric railway tracks.

It is contemplated to obtain water for West Kildonan from the Winnipeg water system, and a 10-inch cast-iron main is to be laid on Jefferson street to be connected to the supply main on McPhillips street and to the distributing main on Main street. I would recommend that three consecutive joints in the 10-inch main be insulated close to where it connects to the supply main on McPhillips street, and that three joints be likewise insulated close to where this main connects to the distributing main on Main street. If in the future, additional connections to the Winnipeg water piping system are made, I would suggest that in all such connections similar insulating joints be installed.

Assiniboia.—This municipality is located west of Winnipeg. Portage avenue, Winnipeg, continues west through it, and a double-track electric railway runs west on the south side of Portage avenue through Assiniboia to Kirkfield, and from here as a single-track line to Headingly, about 9½ miles west of the city limits of Winnipeg. Direct current for this electric railway is supplied from substation No. 3, Winnipeg, so that any stray currents from this railway must return to this substation.

I met Mr. C. W. Rogers, engineer of Assiniboia, and was informed by him that they now have a water piping system comprising about 7 miles of cast-iron mains, and that they expect soon to extend this system by the addition of 12 miles of mains. I also obtained from Mr. Rogers a map showing the layout and locations of the present and proposed water mains of Assiniboia. There is no water main laid on Portage avenue, the buildings on the north side of this street being supplied from a water main in the lane just north of Portage avenue. There is at present no water piping system south of Portage avenue, but it is contemplated to supply the buildings on the south side of this street from a main to be laid in the lane south of Portage avenue. At Woodlawn street, however, one water service from the main north of Portage avenue crosses under the trolley tracks and supplies a building on the south side of Portage avenue. There is also a 6-inch cast-iron lateral from the main north of Portage avenue which crosses the tracks on Portage avenue at Berlin street.

The present water system in Assiniboia is supplied from artesian wells and a pump is located at each well. It is contemplated in the future to obtain water from the Winnipeg water system or from the Greater Winnipeg Water district, but it has not been definitely decided where such connections will be made. I would recommend that when the water piping of Assiniboia is connected to the Winnipeg water piping, or to the mains of the Greater Winnipeg Water District, three consecutive insulating joints be installed in each connecting main near the points of connection, so as to prevent flow of stray currents betweeen the two piping systems.

Transcona.—This municipality lies just east of St. Boniface. I met Mr. W. M. Scott, consulting engineer of the Town of Transcona, and obtained from him a map showing the layout of this town with proposed water and railway lines marked thereon. I also met Mr. Peter Watt, mayor of Transcona, and obtained from him further particulars regarding their proposed water system.

There is at present no water piping system in use in Transcona. About eleven miles of mains are, however, being laid, but no services have been connected to these mains. It is expected that water for Transcona will eventually be obtained from the system of the Greater Winnipeg Water District, which will have a trunk main passing through this town. It is expected that this trunk main will be built either of steel or of reinforced concrete. If connections from the Transcona system are made to an iron or steel transmission main of the Greater Winnipeg Water District, I would recommend that insulating joints be installed in these connections near the transmission main. It is also expected that in the near future an electric trolley railway will be built from Winnipeg to Transcona, but the route of this proposed railway and its source of power are not as yet determined. When this railway is constructed I would recommend that rigid compliance with recommendation No. 12 be required.

SECTION III.—DETAILED REPORT.

CAUSES AND EFFECTS OF STRAY CURRENTS AND REMEDIAL MEASURES.

Stray currents are electric currents shunting through the earth from electrical distribution systems which are grounded at two or more points. These stray currents frequently reach underground metallic structures and corrode them by electrolysis. In practice it is found that the most important sources of stray currents are direct-current electric railways which use the running tracks in contact with ground as part of the electric circuit. In such railways the direct current is usually supplied to the cars from an overhead trolley wire or from a third rail, and is returned to the direct-current supply station by means of the running tracks and negative return feeders. In order to make the running tracks a continuous electrical conductor, the adjoining rail lengths are electrically connected together by some form of rail joint bond. The two rails of a single track and the four rails of a double track should also be cross-bonded at frequent intervals by means of copper cables.

Soil when dry practically does not conduct electric current, but becomes an electrolytic conductor when moist on account of dissolved salts, such as chlorides, nitrates, etc., which are always present. Concrete containing moisture is likewise an electrolytic conductor. Since the rails of direct-current electric railways are ordinarily in contact with earth, part of the return current in the rails will shunt through earth in accordance with the law of divided circuits. If metallic conductors, such as piping systems made up of iron pipes with electrically conducting joints, or lead sheathed cables in underground ducts, lie in the earth through which stray currents pass, such pipes and lead cable sheaths form good conducting paths for these currents, which will therefore be caused to flow on these structures. Since electric current can only flow in a completely closed electric circuit, all stray current flowing on underground pipe and cable sheaths must again leave these pipes and cable sheaths to return to the negative terminal of the generator in the direct-current supply station in order to complete the electric circuit. With the running tracks of the railway connected to the negative busbar of the direct-current supply station in the neighborhood of this station, current in the tracks flows everywhere towards this station. The tracks near the station which are connected to the negative busbar are therefore lowest in potential and the tracks everywhere else are positive in potential to them. With the tracks in contact with earth, currents will flow from the tracks to earth and to underground pipes and cable sheaths at points distant from the power station, and these stray currents will then flow through earth and on underground pipes and cable sheaths towards the station, and will leave the pipes and cable sheaths and flow through earth to the tracks in the neighborhood of the station. At points distant from the station the underground pipes and cable sheaths are therefore negative in electrical potential to the tracks, and these regions are called *negative districts;* in the neighborhood of the station the underground pipes and cable

sheaths are positive in electrical potential to the tracks, and these regions are called *positive districts.* Between the positive and negative districts stray currents flow from the tracks to underground structures or from underground structures to the tracks depending upon the distribution of the cars, etc., thereby causing the potentials of these structures to reverse correspondingly with reference to the tracks. For this reason these intermediate regions are called *neutral* or *reversing districts.* Since all current which leaves the positive terminal of an electric generator must return to the negative terminal, all current which escapes from the tracks in negative districts and reaches underground pipes and cable sheaths must again leave the pipes and cable sheaths in order to return to the railway return circuit. Electricity is in this respect very different from gas, water or oil, which can leak from a pipe and become diffused through earth. Also, for this reason, leakage of current from the tracks of electric railway through earth is not a loss to the railway company; but, on the contrary, by allowing current to return through earth and through underground structures, the conductance of the return circuit is increased and the voltage drop in the return circuit is lowered, so that there is an actual saving in power for the railway company.

Wherever electric current leaves an iron pipe or a lead cable sheath to flow to surrounding soil, electrolytic corrosion of the iron or lead occurs. The mass of metal corroded by electrolysis in a given time depends only on the current, and, with the current densities and other conditions usually met in practice in the case of underground pipes and lead cable sheaths, is equal to that calculated by Faraday's law. This electrolytic corrosion amounts to 20 pounds of iron or 74 pounds of lead per year for each ampere of current leaving the metal to flow to surrounding soil. The applied voltage has no effect on the amount of corrosion produced except in so far as it determines the current; and there is no minimum voltage below which electrolysis does not occur. It must also be understood that this amount of electrolysis corrosion per ampere per year occurs at every point at which current leaves the pipe or cable sheath to flow to surrounding earth, and the same ampere of stray current may leave and again return to a pipe or cable sheath or flow from one underground structure to another underground structure any number of times in its path, depending upon the electrical conditions; for this reason any number of times 20 pounds of iron or 74 pounds of lead may be corroded by a single ampere or stray current in one year.

Commercial irons, steels and cast irons show practically no difference in the mass of metal corroded by electrolysis due to a given current leaving the electrode for a given time. It should be noted, however, that in the case of cast iron the oxides of iron resulting from electrolysis, together with the carbon contained in cast iron, remain in place, leaving the form of the structure unaltered, but with little mechanical strength. In the cases of wrought iron and steels, the oxides of iron resulting from electrolysis usually pass to the surrounding soil. Rapid corrosion by electrolysis from stray electric currents is

usually localized, resulting in pitting of the metal. In this way the pipe or cable sheath is much more rapidly destroyed than if the corrosion occurred uniformly over its surface.

In order to get an approximate idea of the probable damage to iron pipes from electrolysis due to stray currents, the following consideration may be useful. One ampere leaving iron for an electrolyte such as moist soil will in one year corrode at least 20 pounds of iron by electrolysis. From this it can be shown that one milliampere (0.001 ampere) leaving one square foot of iron surface uniformly from the entire surface would corrode in one year a thickness of 0.0005 inch. If this milliampere instead of leaving uniformly from the surface leaves from concentrated areas which represent one per cent. of the total area, pittings having a depth of 0.05 inch will be produced in one year. One milliampere leaving one square foot of pipe surface on the assumption of the action being concentrated upon one per cent. of the surface of the pipe would therefore corrode through and result in a hole in a one-quarter inch wall of an iron or steel pipe in five years. That the assumption of the current leaving from an area equal to only one per cent. of the surface of a pipe is generally warranted, is borne out by my experience in examining a large number of pipes corroded by electrolysis, which has shown that scattered pittings of comparatively small area are almost always found, while the greater part of the iron surface is only slightly corroded.

Lead-sheathed underground telephone, electric light, and power cables are most commonly laid in underground conduits of vitrified clay, concrete, fibre or wood. The soil in which these conduits are buried being more or less wet, moisture will to a greater or less degree get into the ducts and thereby produce electrolytic contact between earth and the lead sheaths of the cables. Since these lead sheaths are relatively thin and since the electrochemical equivalent of lead is nearly four times that of iron, such lead sheathed cables are very sensitive to the electrolytic effects of stray currents. Wherever, therefore, such lead sheathed cables are in underground conduits in localities where substantial stray electric currents are present, it is generally found necessary to provide some measures for protecting them against corrosion and ultimate destruction by electrolysis. The resistance between earth and the lead cable sheaths in ducts can be increased by constructing the ducts so as to be as waterproof as possible, and also so as to drain toward the manholes. It is important also that the manholes be drained wherever this can be done at reasonable cost.

The most commonly used method of protecting lead cable sheaths is to *electrically drain* the sheaths to the return circuit of the railway, so that the current is taken off by metallic conduction and is thus prevented from leaving electrolytically and thereby damaging the cable sheaths. Where *electrical drainage* is employed, it is important that all of the cable sheaths in the conduit system be connected to the drainage cable, and also that the cable sheaths in all manholes be metallically connected together by a copper strap or bond wire. This is necessary in order to prevent considerable potential differences between the sheaths

of the cables in adjoining ducts, which would cause currents to flow between the sheaths of these cables and corrode them by electrolysis.

Drainage connections from cable sheaths should ordinarily not be made to tracks, because a high-resistance joint or joints developing in the tracks may destroy the effectiveness of the drainage connection and may in some cases cause current to flow *to* the cable sheaths instead of *from* them. Such drainage connections should preferably be made either directly to the negative busbar or to a negative feeder cable. The object of drainage connections is to render the cable sheaths throughout slightly negative to surrounding earth and to other grounded structures. If such a drainage connection is found to render the cable sheaths more negative than is necessary for protection, so that they are *overdrained,* it is desired to insert a resistance in series with the drainage connection, and to adjust this resistance and thereby the current drained until the cable sheaths are only slightly negative. In the case of power cables it is especially objectionable to drain an excessive current from the cable sheaths, because this current will heat the sheaths and impair the carrying capacity of the cables. If a cable sheath is rendered highly negative to neighboring structures such as pipes, a tendency for current to flow from the pipes to the cable sheath is set up, causing corrosion of the pipes by electrolysis. In practice it is very frequently found that cable sheaths are overdrained so that they are a source of serious danger to underground piping systems, and trouble from electrolysis of service pipes is commonly experienced where these cross overdrained cables. Overdrainage is often due to the employment of a larger drainage cable than is required at the time in order to provide for future growth, but in such cases a suitable resistance should be inserted in the cable drainage connection, which can be readily adjusted when changes in the railway load make this necessary.

It is preferable to carry a cable drainage connection directly to the railway substation, and there to connect it to the negative busbar through an ammeter and a knife switch. Readings of the ammeter should be taken at least once every day, so that if abnormal conditions develop, they can be reported and the cause determined. Where drainage connections are made to one substation of an interconnected system, and this substation is periodically shut down, the drainage circuit must be opened whenever this station is shut down. Local conditions may necessitate the making of drainage connections to a part of the electric railway circuit whose polarity at times reverses with reference to the cable sheaths. In such a case, an automatic switch should be inserted in series with the drainage connection to keep the drainage circuit closed whenever the cable sheath is positive, and to open this circuit whenever the cable sheath is negative to the drainage connection. In this way current flow from the railway circuit to the cable sheath is automatically prevented. Such automatic switches, though commonly used in situations of this kind, are found in practice to require considerable attention, and it is therefore preferred to make drainage connections to points in the electric railway circuit which are at all times negative to the cable sheaths.

Insulating joints in the lead sheaths of cables have been used in some special cases as protection against stray currents, but these joints must only be used with caution so that potential differences sufficient to harm the sheaths will not be set up across the joints. Such insulating joints in cable sheaths should wherever possible be located in relatively dry places. In some installations insulating joints have been used on individual cable runs in the positive area for the purpose of breaking up the electrical continuity of the lead sheaths and stopping rapid localized destruction from electrolysis, but these joints in such situations will not generally afford permanent and complete protection, and such insulating joints are not generally applicable to cable networks. Special cases arise, however, where insulating joints may be used to prevent current from reaching the sheaths of cable systems. It is found in practice that where an underground cable network has laterals into buildings, considerable currents frequently flow from pipes to the sheaths of the laterals through accidental metallic contacts in the building, and thence to the cable system. Such current flow to the cable system is most effectively stopped by introducing an insulating joint in the sheath of the cable lateral or in the pipe service inside of the building. It is in fact the practice of a number of large telephone companies to install insulating joints in the sheaths of all laterals inside of buildings for this purpose.

Where laterals or sections of cables connecting to the main cable system are carried in iron conduits in negative districts, it is sometimes found that considerable current flows from earth to the iron conduits, thence to the cable sheaths, and so to the cable system. Such current flow can generally be stopped by introducing an insulating joint in the sheath of the cable where it leaves the iron conduit and before it is connected to the main cable system.

In certain localized sections of a cable run it is sometimes found that considerable current flows to the cable sheaths. A common example of this is where a cable crosses a steel bridge in an iron conduit, and where the conduit is in metallic contact with the structure of the bridge and through this with electric railway tracks on the bridge. In such places considerable currents may be caused to flow from the tracks through the bridge structure and the iron conduit to the cable system. In order to stop such flow of current to the cable sheaths, insulating joints have been installed in the cable sheaths on each side of the bridge. The outer ends of the cable sheaths may be connected by an insulated copper cable where necessary to prevent the existence of a dangerous potential difference across them.

A simple and cheap construction of insulating joint for lead cable sheaths, which is extensively used, consists in cutting a narrow band of lead out of the sheath and covering the break with a suitable insulating material so as to prevent entrance of moisture.

Attempts have been made to protect underground pipes from electrolysis by insulating them from earth by paints or dips. Practical

experience as well as a large number of tests have, however, shown that no dip or paint will permanently protect a pipe against electrolysis in wet soil. The first difficulty is to apply the paint so as to form an absolutely perfect coating, and the second one is to prevent mechanical damage to the coating during shipment and installation of the pipe. Experience further shows that even where coatings, paints or dips are apparently intact, electrolytic action is not always prevented, and in fact very serious electrolytic pittings have been produced under apparently good coatings. It has been found that in most cases the applied coatings have either been completely destroyed by the effects of the wet soil and the electric currents, or defects in the coating have developed causing concentrated corrosion at such defective spots. Where it is attempted to apply a heated material like pitch or asphaltum to a cold pipe, it is impossible to completely cover the pipe. Pitch and similar compounds have been applied to pipes with wrappings of jute or of some similar material. A number of layers can be applied in this way so as to build up any desired thickness of insulating covering. Such covering if sufficiently thick will afford protection against electrolysis, provided that it is mechanically perfect. The great difficulty in practice is to install such covering without leaving defective spots through which moisture will have access to the metal of the pipe.

Pipes, where positive to earth, if covered with imperfect insulating coatings or coverings exposing bare spots of metal, are in much greater danger from electrolysis than are bare pipes, for the reason that the stray currents will leave only from these bare spots, and there produce concentrated corrosion. The writer has seen cases where a pipe coated with an imperfect insulating covering was pitted nearly through in one year, whereas a bare pipe in the same locality was very much less affected because the corrosion was distributed over a larger surface.

One form of insulating covering which appears to afford certain protection is a layer of one to two inches of a material like coal-tar pitch, parolite, or asphaltum, of such a grade that it is not brittle and so will not crack, but yet is hard enough to remain in place. The best way to apply such a layer is to surround the pipe with a wooden box, support the pipe upon creosoted blocks of wood or upon blocks of glass, and then fill the space between the box and the pipe with the molten material. When applying this material great care must be exercised to avoid getting stones or dirt into the mixture, and also to avoid leaving bare spots on the pipe. The cost of carrying out such an installation is prohibitive, however, except in very special cases, such as that of service pipes in very bad localities, or that of very important individual pipe lines of small or medium size. Embedding a pipe in cement or concrete, even if this is several inches in thickness, will not protect it from electrolysis, because damp cement or concrete is an electrolytic conductor.

Current flow on metallic pipe lines can be practically prevented by using a sufficient number of insulating joints. A pipe line laid with every joint an insulating joint has a comparatively high resistance and no substantial current can flow on it. It is sometimes possible in the

case of individual pipe lines to use comparatively few insulating joints to break up the electrical continuity of the line and substantially protect it from electrolysis, but such joints must be installed only after adequate tests have shown that sufficient current will not leave the pipe on the positive side of a joint to flow to earth and do serious damage by electrolysis. Insulating joints in pipe lines should not be confined to the positive areas, but should be installed in all places along the pipe line where there is any considerable potential gradient in the earth parallel to the pipe. The frequency with which insulating joints must be installed in a pipe line in order to assure reasonable protection from electrolysis depends upon the potential gradient through earth and upon the electrical resistivity of the soil surrounding the pipe line. A short insulating joint is practically as effective in interrupting the conductivity of a pipe as a long insulating joint, but the latter distributes any leakage current over a larger pipe surface than does a short joint, and hence a long insulating joint is to be preferred wherever there is a considerable potential difference across the joint which is buried in earth, or where the resistance of the surrounding soil is low. The same effect can be practically secured from a short insulating joint by surrounding the joint, and the pipe for some distance on each side of it, with a thick layer of insulating material. In practice such insulating joints and the pipes for a distance of from 5 to 25 feet on each side are frequently covered with a layer of from one to two inches of insulating compound.

Where small service pipes are endangered by current which flows to them either from the main or from house piping, this current flow can be prevented and the pipes protected by placing an insulating joint in such service pipes at the main or in the building.

Where considerable current leaves a relatively short section of pipe and endangers it by electrolysis, this section can be protected by surrounding it with an auxiliary pipe electrically connected to it, so that the current will leave from the auxiliary pipe. This is called *shielding*.

While in a number of American cities electrical drainage has been applied to both the gas and water piping systems as a protection against electrolysis, no complete tests of an extensive electrical pipe drainage system are available so far as the writer is aware. Such tests as have been published consist only of current measurement on the pipes and of potential measurements between the drained pipes and the trolley tracks. The complete data from which to judge the effectiveness of the system would involve the results of many other tests, particularly of measurements of drop across joints in the pipes, and of measurements of potential difference between the drained pipes and other underground structures.

Electrical drainage was first applied to lead cable sheaths, and the success in protecting cable sheaths in this manner led to the attempts to apply the drainage method also to pipes. There are marked differ-

ences between an underground piping system and a lead cable system, however, which render the former much less suited for electrical drainage. The principal difference is that cable sheaths are continuous electrical conductors, while pipes may be more or less discontinuous due to the presence of high-resistance joints. Another difference is that the lead cable sheaths are relatively small and are carried in ducts, which are mostly non-metallic, so that only part of the surface of the cables is in contact with earth, whereas underground pipes are buried directly in earth and generally present enormous contact areas to earth. The result is that when electrical drainage is applied to pipes, the currents on the pipes are very greatly increased, and the danger of current shunting around high resistance joints or leaving the pipe on the positive side of a joint to flow to other structures is correspondingly increased.

If the pipe which is electrically drained conveys an inflammable liquid or gas, or if it passes through a manhole or other confined space where inflammable gases may collect, the flow of stray current on the pipe may involve the danger of an explosion or fire, particularly at times when the continuity of the pipe is interrupted for repairs or for other causes. Many cases have been reported where in interrupting, rejoining, or recalking mains, severe electric arcing was produced.

Where large stray currents flow on the mains of a piping system, large stray currents may also shunt through buildings having both gas and water service pipes, flowing in on one service pipe, passing to the other service pipe through metallic contacts in the building, and then flowing out on this service pipe. Such stray currents through buildings constitute a serious fire hazard.

The complete application of electrical drainage to pipes will involve the drainage of all underground piping systems, and in fact bonding together all underground metallic structures affected by the stray currents, in such a way that at every point where different structures come into proximity in earth, they are brought to practically the same potential. If this is not done there will be at such points a flow of current through the earth from the structure of higher potential to that of lower potential, with resultant corrosion of the former.

When electrical drainage is applied to a single system of underground pipes and without making a complete investigation of the effects of possible high-resistance joints, etc., the installation may be made at relatively small cost, and when so applied, it usually relieves the acute danger from electrolysis in the immediate neighborhood where the drainage connections are made. Both of these considerations have served to favor the electrical drainage system. However, a single drained underground piping system becomes a source of serious danger to other systems. If electrical drainage is applied comprehensively to all underground metallic systems, it will not only be found very expensive to install but likewise expensive to maintain, because as railway and piping systems are changed the drainage system must be changed accord-

ingly. The large increase in current on underground structures produced by electrically draining them also brings about dangerous conditions at scattered and unknown places, which is a serious objection to this method and more than offsets the relief obtained in the neighborhood of the drainage connections.

These considerations as well as practical experience show that no available preventive measures can be applied to an underground piping system, which will protect this system from electrolysis due to stray currents flowing through the earth in the region of the pipes. Theory and practical experience show, however, that the escape of stray currents from direct-current electric railways using the running tracks for return conductors can be reduced to any desired small amount—first, by decreasing the voltage drop in the tracks and thereby correspondingly decreasing the voltage drop through earth and, secondly, by increasing the resistance from tracks to earth. These results may be accomplished by the following means, given in the order of their importance:

(1) By increasing the number of direct-current supply stations in systems extending over large areas, in order to reduce the radius to which any one station supplies current, and also by supplying all of the railways in any locality from one station in this locality.

(2) By increasing the electrical conductance of the tracks, through the use of heavy rails, through the use of low-resistance rail-joint bonds and cross bonds, and through the interconnection of the electric railway tracks of all systems where these come close together.

(3) By removing current from the tracks by insulated return feeders, and by maintaining the negative busbar insulated from ground at the supply station, in all cases where the voltage drop in the tracks would otherwise be excessive. This arrangement is known as the *insulated return feeder system.*

(4) By increasing the resistance between tracks and ground as much as practicable, through draining the roadbed, and, on private right-of-way, through maintaining the tracks out of contact with ground.

These methods are already in general use in England and to a considerable extent also in Germany, and during the last few years they have also been employed in a number of American electric railways. Many years of experience abroad has shown that such improvements in electric railway construction can be practically carried to a point where stray currents through earth from these railways become negligible.

In Great Britain the electric railways are governed by regulations of the Board of Trade, and these include requirements designed to minimize the production of stray electric railway currents through earth, and thus to protect underground structures against electrolysis.

The most important requirement in regard to electrolysis mitigation contained in these British Board of Trade regulations is section 7, which reads as follows:

7. When the return is partly or entirely uninsulated, a continuous record shall be kept by the Company of the difference of potential during the working of the tramway between points on the uninsulated return. *If at any time such difference of potential between any two points exceeds the limit of seven volts, the Company shall take immediate steps to reduce it below that limit.*

It will be seen that this requirement limits the maximum difference of potential between any two points on the track return circuit to 7 volts, and requires records to be kept of this over-all track voltage drop. The Board of Trade interprets the 7 volts not as a momentary maximum reading, but as the mean value between the highest momentary voltmeter reading and the average reading during a period of from 20 to 30 minutes during peak load. In the design of a system the average value for a definite period of time is, however, of more practical value. The highest average for ten minutes during peak load hour affords a close approximation to the interpretation given by the British Board of Trade to the 7-volt figure. This interpretation has also been used in America in a number of cases, and I have also used it in this report.

Paragraph 7 of the British Board of Trade regulations also requires continuous records to be kept of the over-all track voltage drop. This is carried out in practice by means of insulated potential wires from each substation to suitably selected points in the track, with a recording voltmeter placed in each substation and connected successively to these different potential wires. In this way 24-hour records of over-all track voltage drop along the various lines supplied by the substation are obtained. Such potential wires have also been installed on a number of railways in the United States for the same purpose, and they afford the best possible means of obtaining over-all track voltage drop records. The Board of Trade regulations also prescribe a limit for the current density in the rails, which with ordinary rail steel is equivalent to a voltage gradient limit in the tracks of about 0.8 volt in 1000 feet.

British electric railways comply rigidly with the 7-volt limit, and in fact most of these railways operate with over-all track voltage drops not exceeding 3 to 5 volts. Records of track voltage drop are also kept in every railway supply station as required. There are many other requirements in the Board of Trade regulations, but less attention is generally paid to them, paragraph 7 being considered the most important requirement.

The Board of Trade regulations have been in effect for about twenty years, and practically no cases of destruction of underground structures by electrolysis have been reported in Great Britain.

The insulated return feeder system, in conjunction with proper track bonding, usually affords the most feasible means for reducing

track voltage drop in an existing electric railway. In this system feeders insulated from earth are connected from the negative busbar to selected points on the track network. For the best results these feeders should be proportioned for substantially the same voltage drop under average load conditions. If the tracks are to be connected to the negative busbar at the supply station, this must only be done through a resistance proportioned so as to give substantially the same voltage drop as exists in the feeders.

The insulated return feeder system eliminates the concentration of stray current near the supply station, and reduces the track voltage drop, and also diminishes the area over which the leakage of current from the tracks takes place. Since the stray currents through earth depend directly upon the track voltage drop and upon the area over which this leakage occurs, they are reduced in the proportion of the product of these two factors.

The effectiveness of the insulated return feeder system in reducing stray currents through earth is practically independent of the voltage drop in the feeders and consequently of the weight of copper employed. The most economical feeder sizes are those for which the sum of the fixed charges and the cost of their power losses is a minimum.

The insulated return feeder system is frequently confused with the system of *paralleling the tracks* with return feeders, which has been most commonly used in American electric railways. From the standpoint of reducing track voltage drop the two systems are, however, totally different. With copper feeders paralleling the tracks, the voltage drop in the tracks is reduced only in the proportion that the conductance of the track circuit is increased. For example, an amount of paralleling copper equal in conductance to the tracks could at best only reduce the drop in these tracks to one half. It is therefore evident that where the voltage drop in tracks is high, this system would require a prohibitive amount of copper to reduce the voltage drop to reasonably low values. With the insulated return feeder system, on the other hand, the voltage drop in the insulated feeders does not occur in the tracks nor in the earth, and therefore may be made as high as economy dictates. It should be emphasized that with insulated feeders, the tracts in the immediate neighborhood of the power supply station should be connected to the negative busbar only through a suitable resistance, as a direct connection at this point would practically convert the insulated feeder system into a system of feeders paralleling the tracks, because both ends would then be in contact with the tracks and with earth.

With the insulated return feeder system the power losses are larger than they would be if the same amount of copper were employed in parallel with the tracks, but this increase in power losses is a necessary expense, which is fully warranted by the reduction of stray currents through earth, and the corresponding reduction of injury to underground structures.

PROBABLE SOURCES OF STRAY CURRENTS WHICH MAY AFFECT UNDERGROUND STRUCTURES IN WINNIPEG.

The only source of stray currents which may seriously affect underground structures in Winnipeg is the electric railway system of the Winnipeg Electric Railway Company. This railway system was started in 1890, and direct-current power was supplied by a steam generating station located on Assiniboine avenue at Garry street. This steam station continued as the only source of electric power for the electric railways of Winnipeg until 1906, when a substation was placed in operation on Mill street, at the Red River, which received high-voltage alternating currents from a distant hydro-electric plant and from a steam-turbine plant located in the same building with the substation. Since 1906 additional substations have been added, and the old direct-current generating station has been kept as a reserve plant. I am informed that this station has not been in actual operation for a number of years past.

The electric railways of Winnipeg have been extended from time to time to meet the demands of city growth, and now comprise a very extensive single-trolley system operating throughout the principal streets of Winnipeg and extending into adjoining municipalities. The track layout of this system within the city limits of Winnipeg, including St. Boniface and fflmwood, is shown in plate No. 1, as it existed in the summer of 1914, when the tests described in this report were made. Work of laying double tracks was, however, in progress on Arlington street from William to Mountain avenues, and this work was completed late in the fall of 1914. Direct current for operating this railway is at present supplied from six substations as follows:

Substation No. 1, Mill street, at Red River, started June 11, 1906;

Substation No. 2, Osborne street, at Kylemore avenue, started September 5, 1909;

Substation No. 3, Portage avenue, at St. James street, started October 14, 1909;

Substation No. 4, Main street, at Inkster avenue, started December 29, 1909;

Substation No. 8, Logan avenue, at McPhillips street, started November 18, 1912;

Substation No. 10, Assiniboine avenue, at Garry street, started September 25, 1912.

In this railway system current is supplied to the cars by means of positive feeders and an overhead trolley wire, and is returned to the substations through the running tracks, supplemented in the case of three of the substation districts by copper cables paralleling the tracks. The tracks nearest each substation are connected to the negative busbar in the substation by copper cables. In some instances tie cables are also employed, bridging the dicerent sections of the track system.

The locations of the railway substations and of the negative copper cables paralleling and bridging the tracks are also shown in plate No. 1.

It will be noted from plate No. 1 that the tracks of the electric railway pass each of the substations except substation No. 1 and substation No. 10. In the case of substations No. 2, No. 4, and No. 8, the tracks directly at the substation are connected to the negative busbar, and there are no return feeder cables extending beyond the substation. At substation No. 3 the tracks are connected to the negative busbar directly at the station, and in addition to this there is one 500,000-cir. mil negative feeder cable paralleling the tracks on Portage avenue to Minto street, and one 350,000-cir. mil cable crossing the Canadian Northern Railway bridge over the Assiniboine River, and connecting to the tracks on the south side of this bridge. Substation No. 1 is located on Mill street at the Red River, approximately 1,200 feet from the nearest tracks on Main street at Portage avenue. The tracks at this corner are connected to the negative busbar in substation No. 1 by weatherproof cables having a total cross-section of 14,500,000-cir. mils, laid in underground conduits. From Portage avenue paralleling cables extend north to Higgins avenue and south on Main street, connecting to negative cables from substation No. 10, located on Assiniboine avenue, at Garry street, just west of Main street. One 211,600-cir. mil negative cable also extends from substation No. 1 to the tracks in St. Boniface on the east side of the Broadway bridge. Substation No. 10 is connected to the tracks on Broadway, at Garry street, by 2,000,000-cir. mil weatherproof cables laid in underground conduits, and to the tracks on Main street, near Assiniboine avenue, by overhead copper cables, aggregating about 1,500,000-cir. mils in cross-section. From substation No. 10 negative feeders paralleling the tracks also extend north across the Main and Norwood bridges, and west on River avenue, and then south on Osborne street to Corydon avenue. At the Redwood bridge and at the Louise bridge overhead tie cables connect the tracks on the two sides of the bridge. Overhead tie cables also connect the end of the tracks on McPhillips street to the tracks on Selkirk avenue, and the end of the tracks on Bannerman avenue to the tracks on Main street.

The rated output of each of the substations, together with the average current delivered on a normal day, is given in table No. 1.

UNDERGROUND STRUCTURES IN WINNIPEG WHICH MAY BE AFFECTED BY STRAY CURRENTS.

The principal underground structures in the City of Winnipeg which may be affected by stray currents flowing through earth are the underground piping and cable systems. The underground piping systems comprise the transmission and distribution mains for gas and water. These mains consist generally of cast-iron pipes laid with lead joints, which render them extensive metallic conductors in direct contact with earth. The cable systems comprise cables for telephone, electric light and power, electric railway, and fire and police telegraph service. These cables are covered with lead sheaths and are drawn in

underground conduits of vitrified clay, fibre or other material, which a more or less damp, especially at joints. The lead sheaths of these cabl form extensive metallic conductors which are, therefore, in more or le good contact with earth through the ducts in which they lie. Tl following is a brief description of the various piping and cable systen in the City of Winnipeg.

Low-Pressure Water Piping System.—The low-pressure wat piping system is owned and operated by the City of Winnipeg, and i layout is shown in plate No. 2. The first piping of this system was la many years ago, and has been added to from time to time to meet tl demands of city growth, till now it extends through all of the princip streets of Winnipeg and Elmwood. This system supplies water f domestic and industrial uses through service pipes. The water obtained from artesian wells located principally in the northweste part of Winnipeg and also north of the city limits; and the pumpi station for this low-pressure water system is located on McPhilli street, at Higgins avenue. The water mains on the south side of tl Assiniboine River are connected to the mains on the north side by mea of one 8-inch and three 10-inch connecting pipes laid under the rive The water mains of Elmwood are connected to the mains of Winnip by a 12-inch pipe laid under the Red River at Redwood avenue. Tl water mains of the City of St. Boniface are connected to the water mai of Elmwood in Montcalm avenue, at Desalaberry avenue. This lo pressure water piping system comes within the region of stray curren from all of the six railway substations in Winnipeg.

High-Pressure Water Piping System.—The high-pressure wat piping system is also owned and operated by the City of Winnipeg, a its layout is shown in plate No. 3. This high-pressure system exten through the principal business section of Winnipeg and is used for fi service. It was partly installed during 1906 and completed in 191 Water for it is obtained from the Red River, and the pumping stati is located on St. James avenue, near the river. This high-pressu water system comes within the region of stray currents from substatio No. 1, No. 8 and No. 10.

Gas Piping System.—The gas piping system in the City Winnipeg is owned and operated by the Winnipeg Electric Railwa Company. The first piping of this system was laid many years ago a has been extended from time to time to meet the demands of city growt and now extends through all of the principal streets of Winnipeg. Th piping system comes within the region of stray currents from all of tl six railway substations in Winnipeg.

Cable Systems.—There are four principal underground cab systems in the City of Winnipeg, as follows: Manitoba Governme telephone cables, city electric light and power cables, Winnipeg Electr Railway Company light and power cables, and city fire and poli telegraph cables. The first three of these cable systems are carried i independent conduits. The fire and police telegraph cables are carri in the conduits with the telephone cables where such exist, while i

other localities they are carried in independent conduits. There are also a relatively small number of underground telegraph cables belonging to the steam railroads, and these are carried in the telephone conduits.

The lead sheaths of all cables in any one manhole are bonded to each other by copper bond wires. The fire and police telegraph cables and the railroad telegraph cables, where these are in telephone conduits, may therefore be considered as part of the telephone cable system.

The cable systems connect to overhead distributing wires or cables. In the case of the electric light and power distribution system, the overhead conductors generally consist of insulated wire supported on insulators on poles, and therefore these overhead systems are not affected by stray currents in earth. In the case of the telephone cables and of the fire and police telegraph cables, these are generally carried overhead as lead covered cables suspended from steel messenger wires. These messenger wires are grounded at intervals by means of ground plates for high voltage protection. These overhead lead covered cables are therefore connected at intervals with earth and may receive or deliver current from or to earth over these ground wires.

The most extensive underground cable system is that of the Manitoba Government Telephone Commission, which extends quite generally throughout Winnipeg and comes within the region of stray currents from all of the six railway substations.

The city electric light and power distribution system is laid underground only in the center of the city, whereas the high-tension feeder cables extend underground along Higgins avenue to the city electric power substation at McPhillips street. The underground city electric light and power cables come within the region of stray currents from substations No. 1, No. 8 and No. 10.

The fire and police telegraph system comprises underground cables scattered quite generally throughout Winnipeg, and they come within the region of stray currents from all of the six electric railway substations.

The layout of all of the above underground cable systems is shown in plate No. 4.

SCOPE AND METHODS OF SURVEY.

For a number of years past, numerous potential measurements of underground pipes and cable sheaths referred to trolley tracks have been made by the City Electrical Department and by the Manitoba Government Telephone Commission, and copies of the results of a large number of such tests have been furnished me. During the early spring of 1914, prior to the beginning of my investigation, the following tests were made and the results were appended to the briefs submitted to the Commission:

Potential survey of water pipes referred to street railway tracks, made generally throughout Winnipeg by the city electrical department;

Measurements of track voltage drop in the neighborhood of each railway substation, made by the city electrical department;

Potential survey of telephone cable sheaths referred to street railway tracks, made by the Manitoba Government Telephone Commission;

Measurements of track voltage drop, made by the Winnipeg Electric Railway Company.

At the beginning of my investigation I made a careful study of the results of all of these tests, and in this way obtained a good general idea of the electrolysis situation in Winnipeg. I found, however, that there were certain inconsistencies in the data presented, and that in many respects the data were incomplete, current measurements on underground pipes and cable sheaths being for example entirely lacking. It, therefore, became necessary to lay out a series of tests to be made on the railway system and on the various underground structures which might be affected by electrolysis, so as to obtain complete and satisfactory data upon which to base conclusions.

Before beginning my investigation, skeleton maps of Winnipeg drawn to a uniform scale were prepared at my request by the various interests showing the layout of the following structures:

Tracks of the Winnipeg Electric Railway Co. with locations of substations;

Low-pressure water mains;

High-pressure water mains;

Underground gas pipes;

Manitoba Government Telephone Commission underground cables;

City electric light and power department underground cables;

Winnipeg Electric Railway Company underground electric light and power cables.

City fire and police telegraph department underground cables;

During the progress of my investigation the following additional drawings were furnished me by the Winnipeg Electric Railway Company:

Skeleton railway map showing layout of positive feeder cables;

Skeleton railway map showing layout of negative feeder cables;

Skeleton railway spot map showing locations of cars during peak load schedule;

Set of drawings showing negative feeder connections at substations;

Set of drawings showing details of cross-bonding and jumpers at special work in tracks and on bridges;

Detail drawing of underground mains and structures at corner of Main street and Portage avenue;

Layout of Winnipeg Electric Railway Company conduit system; I also obtained from the city engineer's office a large scale drawing of the underground water pipes in the neighborhood of the pumping station in McPhillips street.

The following are the principal tests undertaken during this investigation:

(1) Current delivered over each positive feeder at each substation during a normal day;

(2) Measurements of track voltage drop in each substation district;

(3) Potential measurements between various underground pipes and cable sheaths and between these structures and electric railway tracks;

(4) Current flow on underground water pipes;

(5) Current flow on lead sheaths of underground cables;

(6) Current flow in existing electrical drainage connections from underground cable sheaths to the railway return circuit.

From estimated resistances of the track circuit and from the measured currents delivered by the substations, the over-all track voltage drops were also computed, and the results compared with the measured values. In each substation district, simultaneous measurements of potential difference between the water pipes and tracks were also made at the two points between which the track drop was being measured. From these three simultaneous voltage measurements the drop in the water mains between the two points was computed.

A large number of measurements of voltage drop across rail joints and track special work were also made at scattered points throughout Winnipeg, but no complete investigation of track bonds was undertaken. The reason for this was that systematic tests of track bonding necessarily consume a large amount of time, and records of such tests made by the Winnipeg Electric Railway Company were available for my information. The railway company also informed me that it had repaired all broken bonds found during the course of its rail bond tests. Furthermore, the computations and measurements of track voltage drop which I made would indicate whether the track bonding was generally good or generally defective.

In order to measure the current flowing on a pipe it is necessary to connect the terminals of a millivoltmeter across a continuous length of the pipe and measure the drop in potential due to the current. This

test requires exposing a length of pipe. From this drop and from the calculated resistance of the included length of pipe, the current flowing on the pipe is obtained. In order to be able to repeat the current measurements on these mains at any future time without again having to make an excavation, two insulated wires were permanently connected to the exposed pipe length, and the ends brought to the surface in service boxes to form permanent electrical test stations. The locations and current constants of these electrical test stations on the low- and high-pressure water mains in Winnipeg are given in tables No. 10 and No. 11 respectively.

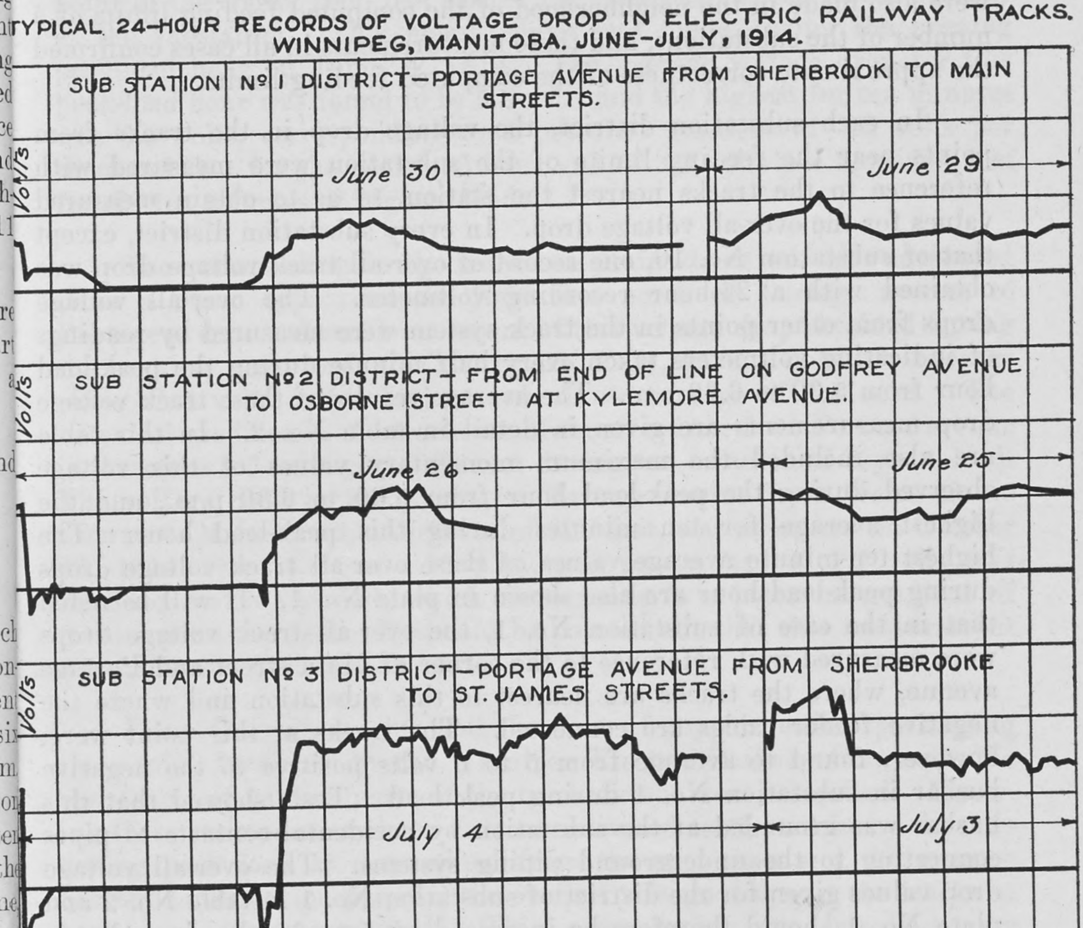
The tests of potential differences and of voltage drop in pipes were made with Weston indicating meters and with a Bristol smoked-chart recorder, which could be arranged so as to give either a 24-hour or a 1-hour record.

The underground cables are accessible in frequent manholes, and tests on the cable systems were therefore made in the manholes.

INVESTIGATION AND TESTS RELATIVE TO ELECTRIC RAILWAY SYSTEM.

The current output and current distribution were obtained for each railway substation from readings of the switchboard ammeters connected in the positive feeders leaving the station. These current readings were taken at one-half minute intervals in each of the six railway substations during the peak-load hour from 5.30 to 6.30 p.m. on June 24, 1914. The average current output of each substation for this peak-load hour and the highest average value during ten minutes of this hour are given in table No. 1. The bus voltages of the various stations were also noted every half minute during this time and their average values are included in table No. 1. The current delivered from each substation by every feeder was also noted every five minutes from 6 a.m. until midnight on June 25, 1914, and the average daily output thus obtained for each station is also included in table No. 1. Both June 24th and 25th were considered to be fair representative business days.

The locations of cars during peak-load schedule was furnished me by the Winnipeg Electric Railway Company in the form of a spot map, in which dots placed on a skeleton railway map indicated the locations of cars during peak load. The total number of cars operating in the six railway substation districts on June 24th, excluding those on Main street north beyond the city limits, was 270. The total current supplied by all of the substations for the operation of these cars during the ten minutes of highest load on this day was 15.380 amperes. From this the average current consumption per car during peak load is found to be 57 amperes. From the spot map giving the location of cars during the peak load and the above computed average value of current consumed per car, and the current delivered to the track system by all of the substations during peak load on June 24th, a normal business day, the approximate feeding limits of each substation were determined.


TYPICAL 24-HOUR RECORDS OF VOLTAGE DROP IN ELECTRIC RAILWAY TRACKS.
WINNIPEG, MANITOBA. JUNE-JULY, 1914.
SUB STATION Nº 1 DISTRICT—PORTAGE AVENUE FROM SHERBROOK TO MAIN STREETS.
Volts
June 30
June 29
SUB STATION Nº 2 DISTRICT— FROM END OF LINE ON GODFREY AVENUE TO OSBORNE STREET AT KYLEMORE AVENUE.
June 26
June 25
SUB STATION Nº 3 DISTRICT—PORTAGE AVENUE FROM SHERBROOKE TO ST. JAMES STREETS.
July 4
July 3
SUB STATION Nº 4 DISTRICT—FROM SELKIRK AVENUE AT McGREGOR STREET TO MAIN STREET AT INKSTER AVENUE.
July 3
July 2
SUB STATION Nº 8 DISTRICT—FROM SELKIRK AVENUE AT McGREGOR STREET TO LOGAN AVENUE AT McPHILLIPS STREET.
June 27
June 26
Time
12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
Noon
Night
Fig. 1

Measurements of voltage drop and its direction in short lengths of trac were also made in the neighborhood of the computed feeding limits of number of the substations, and these measurements in all cases confirme the approximate correctness of the computed feeding limits.

In each substation district, the voltage drop in the tracks fron points near the feeding limits of the substation were measured wit reference to the tracks nearest the station, so as to obtain measure values for the over-all voltage drop. In every substation district, excep that of substation No. 10, one record of over-all track voltage drop wa obtained with a 24-hour recording voltmeter. The over-all voltag drops from other points in the track system were measured by reading of indicating voltmeters taken every half minute during the peak-loa hour from 5.30 to 6.30 p.m. The average results of these track voltag drop measurements are given in detail in table No. 2. In this tabl are also included the maximum momentary values of this voltag observed during the peak-load hour from 5.30 to 6.30 p.m., and th highest average for ten minutes during this peak-load hour. Th highest ten-minute average values of these over-all track voltage drop during peak-load hour are also shown in plate No. 1. It will be note that in the case of substation No. 1, the over-all track voltage drop were measured with reference to the corner of Main street and Portag avenue, where the tracks are nearest to this substation and where th negative feeder cables are connected. The tracks at this point were however, found to average from 5 to 6 volts positive to the negativ busbar in substation No. 1 during peak load. Tests showed that thi busbar was grounded at the substation by accidental contacts to pipe connecting to the underground piping systems. The over-all voltag drop values given for the district of substation No. 1 in table No. 2 an plate No. 1 should therefore be increased by 5 to 6 volts, in order t obtain the true voltage drop in earth which affects undergroun structures.

At my request the ground connection of the negative busbar i this substation was located and removed during the summer of 1914 and after I returned to Winnipeg in October, 1914, tests made showe that the negative busbar in this substation is now substantially insulate from earth. The former drop of from 5 to 6 volts between the grounde tracks at the corner of Portage avenue and Main street and the eart contact at the Mill street substation has therefore now been removed.

One 24-hour record of over-all track voltage drop for each sub station district, except that of substation No. 10, is shown plotted i figure 1. The characteristic variations of this track voltage drop in eac substation district are well shown by these records. It will be note from table No. 2 and from plate No. 1 that the over-all track voltag drop is very high in nearly all of the substation districts, showing in a number of cases over 20 volts for the highest ten-minute average durin peak-load hour.

In order to obtain the potential gradient in the tracks on Portag avenue east of substation No. 3, the voltage drop was measured from a

point in the tracks 1650 feet east of the substation to the tracks directly at the substation. This measurement was made during the evening peak-load hour on June 24, 1914. The average voltage drop for this peak-load hour was found to be 5.3 volts and the highest for ten minutes was 6.5 volts, corresponding to a potential gradient of 3.2 volts per thousand feet for the peak-load hour and of 3.9 volts per thousand feet for the ten minutes of highest load.

The voltage drop in the tracks on Main street was also measured from a point approximately 1000 feet north of Portage avenue to Portage avenue. A one-hour record of this voltage drop obtained during the evening peak load on October 22, 1914, gave a one-hour average value of 4 volts and a highest ten-minute average of 4.5 volts. The potential gradient in the tracks on Main street north of Portage avenue is therefore 4.5 volts per 1000 feet during ten minutes of highest load. The voltage drop in the tracks on Portage avenue from Notre Dame avenue to Main street, a distance of 250 feet, was measured on October 28, 1914, from 4.00 to 4.15 p.m., and an average of 1.5 volts was obtained for this period, which corresponds to a potential gradient of 6 volts per 1000 feet. It should be pointed out that this measurement was not made during peak load.

From the rail weights and the sizes of copper feeders paralleling these rails, furnished by the Winnipeg Electric Railway Company, the resistances of various parts of the track circuit were computed. Knowing these resistances and the current delivered to the tracks by the cars during peak load as determined from the spot map and the average current consumption per car, the over-all voltage drops in the tracks at peak load were computed. This computation was based on the assumption that the rail bonding was perfect, and that all of the return current remains in the tracks. Since the current values used in the computations are the highest averages during ten minutes of the peak-load hour, the computed voltages are correspondingly the highest ten-minute average values during the peak-load hour. The results of these computed over-all track voltage drops are given in table No. 3.

In this table the measured values of the highest average track voltage drop for ten minutes during peak-load hour are also given for convenient comparison with the computed values. It will be noted that in all but a few cases the computed values of over-all voltage drop are considerably higher than the measured values. A notable example of this is found in the tracks running west on Portage avenue from substation No. 3, where the computed over-all voltage drop is 44 volts, and the measured drop is 26 volts. The lower measured values found are undoubtedly due to the fact that a considerable part of the current shunts from the tracks to earth. This is confirmed by tests on Portage avenue west from substation No. 3, where both the water main and the underground cable sheaths were found to carry abnormally large stray currents. In the few cases where the computed values of over-all voltage drop are less than the measured values, this is probably due to

defective rail bonds which would increase the resistance of the tracks above the value assumed in the computations.

The fact that in most cases the computed over-all voltage drops are higher than the measured drops is an indication that the rail bonds and the jumpers across special work are generally in good condition. This is confirmed by a large number of tests of voltage across rail joints and special work, made at various points throughout Winnipeg, which in every case gave low values.

TESTS RELATING TO WATER PIPING SYSTEM IN WINNIPEG.

The low- and high-pressure water piping systems in Winnipeg are buried in earth and are generally accessible for electrical tests only through hydrants and house service connections. Such connections are satisfactory for measuring the potentials of the pipes referred to other underground structures, but cannot be used for measuring the current flowing on the mains. For this purpose it is necessary to make electrical contacts to two points on a continuous length of pipe not including a joint. In Winnipeg such connections for current measurements were available only in a few places where the mains happened to be exposed for other purposes. In order to obtain an estimate of the magnitudes of stray currents flowing on the low- and high-pressure water piping systems, pipe lengths of both systems were especially exposed at a number of selected locations in each substation district. Owing to the severe winters prevailing in Winnipeg, the water mains are generally laid about eight feet below the street surface so as to be below the frost line; this makes excavation work unusually expensive; the principal streets of the city are also paved with permanent and expensive pavement, and it was therefore desirable to cut into this pavement only when absolutely necessary. For these reasons current measurements on the water mains could be made only at relatively few places, so selected as to require as little cutting of the permanent pavement as possible. A sufficient number of excavations for such current measurements in each substation district were made, however, to enable me to form a good idea of the directions and general magnitudes of the currents flowing on the low- and high-pressure water mains throughout Winnipeg.

No special attempt was made to expose water mains in places where electrolysis was thought to be developing, because this always requires a considerable amount of excavation, which was not practicable under the existing conditions. Furthermore, most of the substations in the neighborhood of which electrolysis of underground pipes is known to be going on, have been in operation for only a relatively few years; so it was not expected that very severe corrosion of the iron pipes would have developed by this time.

While I was in Winnipeg a number of excavations were made in order to repair breaks in the water piping system, some of which were caused by electrolysis. At all such locations, as well as at every location

where a water main was exposed expressly for current measurements, I made a personal examination and tests directly on the exposed main. In most of the excavations exposing water mains the soil consisted of heavy loam or clay which was generally very wet; in fact in many cases the water collecting in the bottom of the excavation had to be pumped out before an examination of the main could be made. It should be pointed out that the locations selected for exposing mains for current measurements were in neutral or negative districts where currents were likely to be the largest, but where the pipes were not thought to be affected by electrolysis, except in special cases such as high-resistance joints or where current leaves to flow to a neighboring structure in earth. It was noticed that at these places, where from a study of the electrical conditions electrolytic corrosion of the main would not be expected, the mains were generally in good condition, and did not show graphitic pitting, proving that Winnipeg soil does not itself produce graphitic pitting without the action of electrolysis from stray currents. In a few places, special conditions were noticed, and these are briefly described in the following.

Academy road, between Assiniboine River and Wellington Crescent, July 9, 1914.—One length of 10-inch cast-iron low-pressure water main was exposed. This main was laid in 1905. A measurement on this main at 2.45 p.m. showed an average current of 5.4 amperes flowing north. A 12-inch cast-iron gas main was also exposed in this excavation. A current measurement on this gas main showed an average current of 1.9 amperes also flowing north. The water main was 0.1 volt negative in potential to the gas main. Both pipes appeared to be in good condition.

Arthur street, south of McDermot avenue, July 7, 1914.—One length of 10-inch cast-iron high-pressure water main and two joints were exposed. This main was laid in 1906. No measurable drop was found in 10 feet of continuous pipe, but a drop of 20 millivolts was found across one joint and 10 millivolts across a second joint. The edge of the bell of one joint was found to be badly graphitized and one graphitic pit about ⅛-inch deep was also found in the body of the main. The two joints evidently have a high electrical resistance tending to cause stray current to shunt around them.

Main street, northwest corner of Portage avenue, July 4, 1914.—A leak occurred in the high-pressure main at this point and a portion of this main was exposed for repairs. It was found that the leak was due to a defective joint and it was repaired by recalking. The 12-inch high-pressure mains on Portage avenue and Main street are connected together through a tee-connection, and this tee together with about one foot of the main on Portage avenue was exposed in the excavation. The soil was clay and quite wet. An examination showed that the bells of the tee and pipe were very badly graphitized so that the edges could be easily cut with a knife to a depth of ¼-inch. The portion of main exposed also showed several soft spots from which graphitic material could be readily removed. A portion of a 4-inch low-pressure water

main and of a 12-inch gas main were also exposed in this excavation, and both of these mains showed considerable graphitic action. When the surface of the gas main was scraped a distinct smell of gas was noticed; and in fact there was a strong smell of gas in the excavation. The high-pressure main was found to be of the same potential as the low-pressure water main and the gas main, and about 1 volt positive to the trolley tracks. The pipes were also about 0.5 volt positive to the sheaths of the cables in nearby conduits. These potentials are now quite low, but were formerly much higher. Further, there are so many pipes and other underground metallic conductors at this corner, that the resistance of the path from the pipes to the trolley tracks and to the lead cable sheaths, both of which are here electrically connected to the railway return circuit, must be quite low; the trolley tracks at this corner are in fact at the lowest potential for the district of substation No. 1, so that there is a strong tendency for currents in the piping system to concentrate towards this corner and to leave the pipes in order to return to the railway return circuit. The graphitic pitting found is undoubtedly due in part to former conditions and in part to present conditions.

McPhillips street, at Jarvis avenue, July 6, 1914.—One length of 18-inch cast-iron low-pressure water main was exposed. This main was laid in 1905. The soil is yellow clay. At 6.40 p.m. an average current of 6.2 amperes was found on the main flowing south. The body of the main appeared to be in good condition and did not show graphitic action. The bell of the joint which was also exposed showed, however, deep graphitic action at its edges. A drop test across the joint showed the bell side, which was the north side of the joint, to be 150 millivolts positive in potential to the south or spigot side. This indicated that this joint has a high electrical resistance, so that current shunts around it and produces the graphitic action at the edges of the bell. The fact that the body of the pipe was not affected proves that the graphitic pitting of the bell was caused by electrolysis.

Mill street, just north of substation No. 1, July 6, 1914.—One length of the 4-inch cast-iron low-pressure water main which supplies the substation was exposed near the manhole in front of the substation. A 4-inch cast-iron gas main was also exposed in this excavation. At 9.30 a.m. an average current of 7.5 amperes flowed towards the substation on the water main, and an average current of 9.6 amperes flowed towards the substation on the gas main. A drop of 60 millivolts was found across one exposed joint in the water main. The water main was 90 millivolts positive to the gas main and 0.6 volt negative to surrounding soil. It was also found to be 50 millivolts negative in potential to the cable sheaths and to the negative feeder cables to which these cable sheaths was connected in the adjoining manhole. In the substation the water and gas pipes were found to be only about 0.8 volt positive to the negative busbar during the peak-load hour. These voltage measurements indicated that the water and gas pipes were connected to the negative busbar in the substation. A voltage measurement made on June 29, 1914, also showed the low-pressure

water pipe at Portage avenue and Main street to average 6 volts positive to the water piping in substation No. 1 during the peak-lead hour from 5.30 to 6.30 p.m. This indicates that there was a strong tendency for current to flow through earth towards substation No. 1.

Osborne street, at Kylemore avenue.—A lead water service pipe into substation No. 2 was pitted causing it to leak and necessitating its replacement in July, 1914, while I was in Winnipeg. Potential measurements showed that the water piping here is highly positive to the trolley tracks and to earth, so that the corrosion and pitting was undoubtedly caused by electrolysis from stray current leaving the pipe to return to the substation. I am informed that this service pipe had also been replaced a couple of years before, owing to the corrosion by electrolysis.

Osborne street, east side of street, south of Morley avenue, October 24, 1914.—A lead water service pipe crossing the street had developed a leak under the tracks, and was disconnected at the main. A new service pipe was installed from the water main on the west side of Osborne street, so as not to cross under trolley tracks. The destroyed service pipe under the tracks was not removed and therefore the cause of the leak could not be positively determined. One length and one joint of the 6-inch low-pressure water main on the east side of the street was exposed where the old service pipe had been cut off. This length of pipe was found to be badly graphitized and pits $\frac{1}{4}$-inch in depth could be dug out with a knife. The edge of the bell was also deeply graphitized. Electrical measurements made at 11.30 a.m. showed an average current of 2.1 amperes flowing south, and showed the main to average 3 volts positive in potential to the trolley tracks. At Woodward avenue, which is five blocks north of Morley avenue, this main was found to carry a larger current flowing south, indicating that current was leaving it at points south of Woodward avenue. This is in accord with the potential measurements. The graphitic pitting of the main has therefore been caused by electrolysis from stray current leaving the main. It is also probable that the service pipe was destroyed by electrolysis from stray current flowing from it to the street railway tracks.

Pacific avenue and C.N.R. right-of-way, January 14, 1915.—A report by City Electrician Cambridge to the Commission, dated January 15, 1915, states that a $\frac{5}{8}$-inch lead pipe which was part of the service connection from the low-pressure water main at the foot of Pacific avenue, supplying the light and power department stores at the foot of James street, had burst on January 14, 1915, at a point just east of the transfer tracks. This service pipe was laid in Augut, 1912. A 2-inch Pintsch gas pipe is laid underground along the railroad right-of-way west of these transfer tracks from Point Douglas avenue to Broadway. Mr. Cambridge, in his report, states that the portion of the service pipe which was destroyed had the appearance of having been damaged by electrolysis, but that no electrical tests had been made except on the transfer tracks in which no current flow was found. This Pintsch gas

pipe was connected to the return circuit of the electric railway at the Mill street substation until this connection was removed at my request in July, 1914. Mr. Cambridge in his report expresses the belief that this water service pipe was destroyed by stray current flowing to the Pintsch gas pipe, and states that he is apprehensive that other water service pipes crossing or adjacent to this Pintsch gas pipe may also have been damaged in the same manner. At my request, Mr. George L. Guy made electrical measurements jointly with Mr. R. H. Long of the Winnipeg Electric Railway Company and with Mr. H. M. Smith, of the city electrical department, on February 24, 26 and 27, 1915, under two conditions, namely, with the drainage connection from the Pintsch gas pipe to the railway return circuit at the Mill street substation open, and with this drainage connection temporarily closed. For these tests the Pintsch gas pipe and the water service pipe were exposed; the gas pipe was in frozen soil, while the water service pipe was below the frost line. The average results of these measurements as reported to me by Mr. Guy are tabulated below:

	Pintsch Gas Drainage, Open.	Pintsch Gas Drainage, Closed.
Current on lead service pipe at point 18 feet west of crossing with Pintsch gas pipe, Feb. 24th, 1915, 10.15 a.m., amperes	0	0.3 Flow E.
Potential of lead water service pipe referred to Pintsch gas pipe, Feb. 26th, 1915, 3 p.m., volts..	-0.19	+ 2.0
Momentary current in a temporary bond connection from lead water service pipe to Pintsch gas pipe, Feb. 26th, 1915, 3.40 p.m., amperes............	—	6.0

The results of these tests indicate quite clearly that with the drainage connection from the Pintsch gas pipe to the railway return circuit closed, as it formerly existed, the water service pipe was highly positive in potential to this Pintsch gas pipe, and there was actually current on the former flowing towards this gas pipe. It is, therefore, clear that the electrical drainage connection from the Pintsch gas pipe near the Mill street substation tended to cause current to leave this water service pipe at Pacific avenue and probably caused the destruction of this service pipe by electrolysis, and similarly endangered other water service pipes crossing or adjacent to this Pintsch gas pipe. This positive potential condition of the destroyed water service pipe, and the current flow on it, do not exist at present with the drainage connection from the Pintsch gas pipe open.

Portage avenue, southwest corner of Fort street.—During July there was an extensive excavation made on the west side of Fort street at the corner of Portage avenue where an underground lavatory was being constructed. In this excavation a number of lengths of 4-inch cast-iron water main were exposed. An examination showed that this main was very badly corroded and pitted so that in many places, particularly at the joints, the material of the pipe had become graphitized and deep pits could be dug out with a knife. The pipe at this point was slightly negative to earth. Before the outlying railway substations were placed in operation, however, this was a highly positive

Corroded Cast-Iron Connecting Pipes from High-Pressure Water Main Removed from Portage Avenue at Hargrave Street, October, 1914

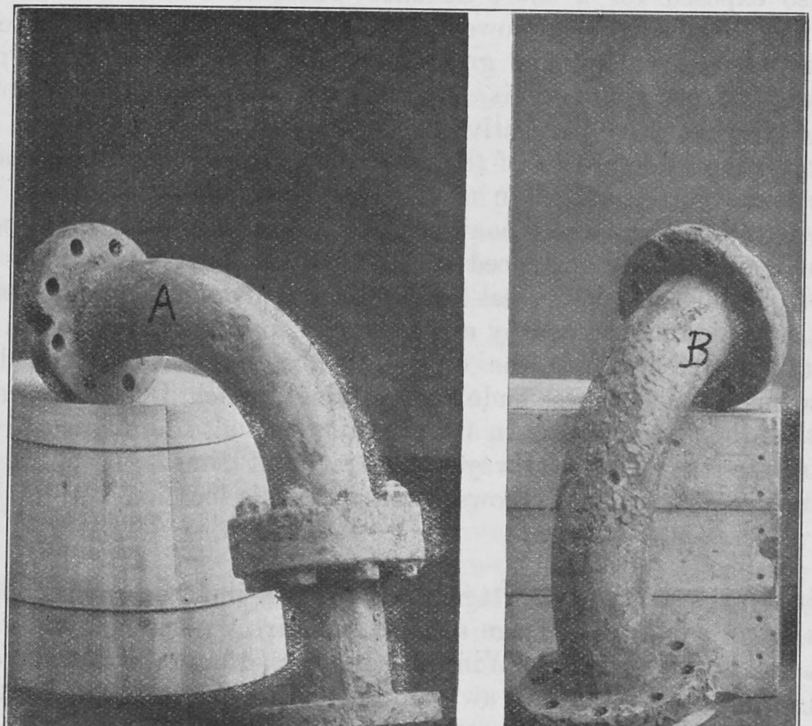


Fig. 2

region, and it is probable that this main was corroded to its present state by electrolysis at that time.

Portage avenue, corner of Hargrave street, October 29, 1914.—An 8-inch cast-iron connection from the 12-inch high-pressure water main connects to a hydrant at this point, and from this 8-inch pipe a 4-inch cast-iron pipe with several elbows and flanged joints was connected to a street sprinkler plug. These were laid in 1907. A leak had developed in this sprinkler connection, and it, together with a portion of the 8-inch pipe, were exposed for examination and repairs. It was found that the elbows of the 4-inch connection were badly pitted and graphitized, particularly at the edges of the flanges. The 8-inch hydrant connection was also pitted at a number of points, and several pits $\frac{1}{8}$-inch deep were dug out with a knife. This 8-inch pipe was also exposed for a short distance where it crosses the conduits containing lead-sheathed power cables of the Winnipeg Electric Railway Company, and one graphitic pit was found in this pipe at this point of crossing. This high-pressure pipe was found at 3.05 p.m. to average 1 volt negative to the street car tracks but 2 volts positive to the lead sheaths of the railway cables which run in conduits on the same street and close to the high-pressure water main. The graphitic condition of the elbows and the graphitic pits in the pipe are such as are generally produced by electrolysis, and it is evident that at least part of this pitting has been produced by stray current leaving the pipes to flow to the nearby cable sheaths; part of the corrosion may have taken place before the outlying substations were started up, because potential surveys made at that time, which I have examined, show that the water piping in this vicinity was also highly positive in potential to the street railway tracks at that time. A photograph showing two of the pitted elbows taken from this location is reproduced in fig. 2.

St. James street, at Portage avenue.—A 6-inch water main on St. James street south of Portage avenue and directly opposite substation No. 3, broke while I was in Winnipeg in June, 1914. The direct cause of the break was the falling away of the soil underneath the pipe due to the construction of a new sewer sometime before. A length of the main which was removed showed considerable graphitic action, and deep pits could be dug out with a knife. An examination and tests made by me on June 27, 1914, showed that the two lengths of pipe adjoining the one which had been replaced, also showed deep graphitic action, the edges of the bells being easily cut with a knife. Electrical measurements made at 10.00 a.m. showed that this main was carrying an average current of 8.8 amperes flowing south, and that the main was from 6 to 10 volts positive in potential to the tracks on Portage avenue. These two lengths of pipe were, therefore, also removed and replaced with new pipe on my recommendation. An examination of these two lengths of pipe after they were removed, showed that there were many graphitic pits, some at least 2 sq. in. in area and half way through the wall of the pipe, and a few nearly all the way through the wall of the

pipe. A photograph of one of these lengths of pipe is reproduced in fig. 3.

Corroded Low-Pressure Water Main Removed from St. James Street at Crossing of Portage Avenue, June, 1914

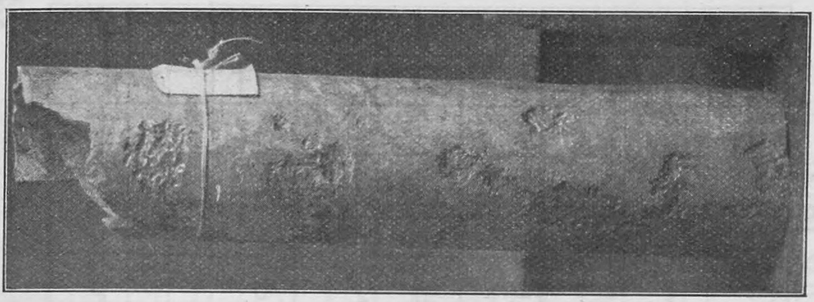


Fig. 3

General measurements on water piping system.—At every location where a sufficient length of water main was exposed for making a current measurement, a permanent electrical test station was established, by means of which these measurements can be made at any future time without again exposing the main. At these permanent test stations current measurements were made on the water mains by means of a smoked-chart recording millivoltmeter using either a 24-hour or a 1-hour chart. The maximum, minimum, and average values of the currents on the low-pressure water mains are given in table No. 6, and the average values of these currents are shown in plate No. 2. The maximum, minimum, and average values of the currents on the high-pressure water mains are given in table No. 7, and the average values of these currents are shown in plate No. 3. It will be seen from tables No. 6 and No. 7, and from plates No. 2 and No. 3, that at nearly every location where a current measurement was made on a low- or high-pressure water main, stray currents of substantial magnitudes were found flowing towards the nearest railway substation. A particular striking example on this is the case of the high-pressure water mains on Alexander and McDermot avenues, at Arlington street, shown in plate No. 3. On both of these mains current flows west toward McPhillips street. This total current of about 20 amperes must leave the high-pressure mains on Alexander and McDermot avenues west of Arlington street and on McPhillips street and must produce corresponding corrosion of the high-pressure main by electrolysis. On Alexander avenue at Stanley street and on McDermot avenue at Hargrave street, both near substation No. 1, the current flow on the high-pressure water mains is east, that is towards this substation, as seen from plate No. 3.

Three 24-hour records of current flow on water mains are shown plotted in fig. 4. These records are typical of all current records that were obtained on the water mains. Comparing these current records with the records of voltage drop in the street railway tracks, shown in fig. 1, the striking similarity between the records of current flow on the

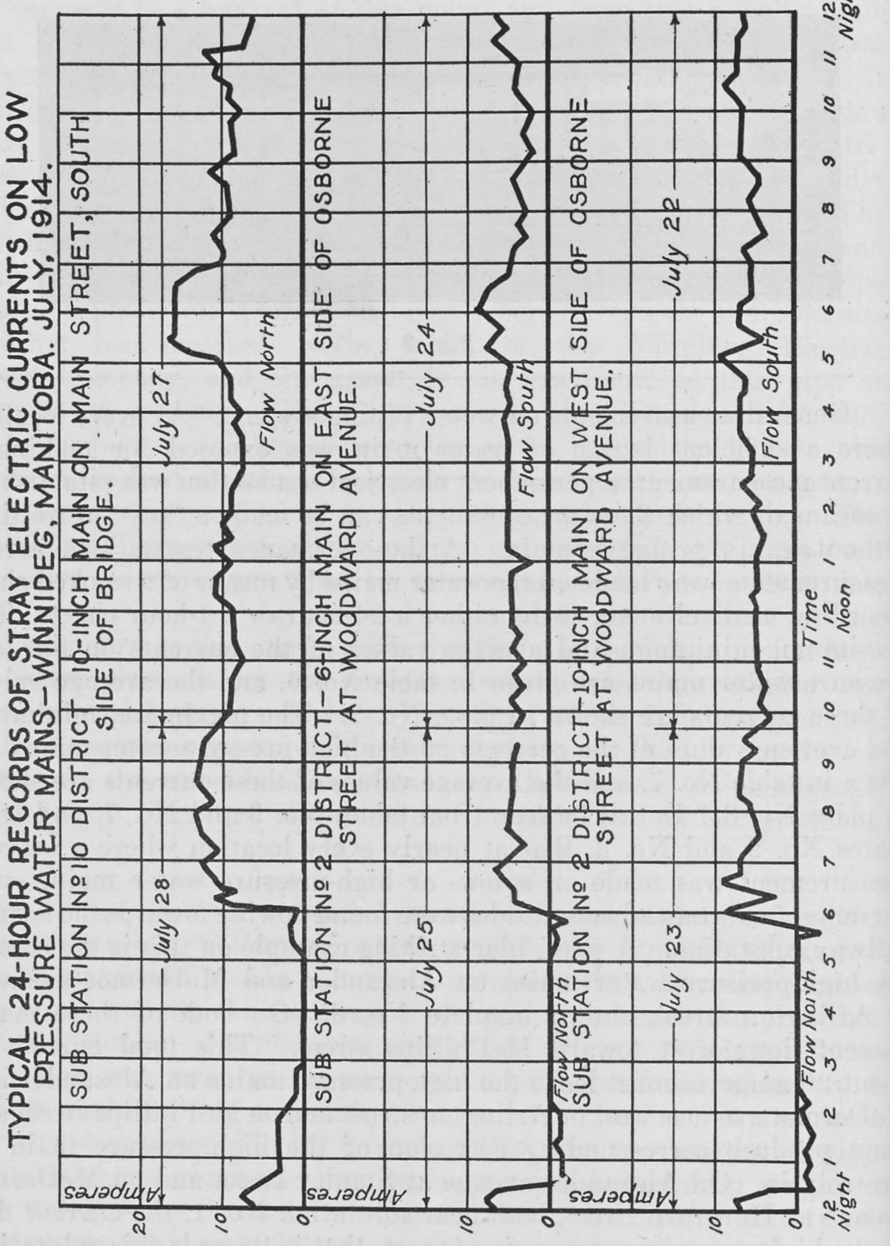

TYPICAL 24-HOUR RECORDS OF STRAY ELECTRIC CURRENTS ON LOW PRESSURE WATER MAINS—WINNIPEG, MANITOBA. JULY, 1914.
SUB STATION Nº 10 DISTRICT—10-INCH MAIN ON MAIN STREET, SOUTH SIDE OF BRIDGE.
SUB STATION Nº 2 DISTRICT—6-INCH MAIN ON EAST SIDE OF OSBORNE STREET AT WOODWARD AVENUE.
SUB STATION Nº 2 DISTRICT—10-INCH MAIN ON WEST SIDE OF OSBORNE STREET AT WOODWARD AVENUE.
July 28
July 27
July 25
July 24
July 23
July 22
Flow North
Flow South
Flow North
Flow South
Amperes
Amperes
Amperes
20
10
0
10
0
10
0
12 Night
1
2
3
4
5
6
7
8
9
10
11
12 Noon
1
2
3
4
5
6
7
8
9
10
11
12 Night
Time

Fig. 4

water mains and of track voltage drop is shown, proving conclusively that the current on the water mains is stray current from the electric railway. This is still more markedly seen from fig. 5, where a 24-hour record of current flow on the 10-inch low-pressure water main on Portage avenue west of the subway,

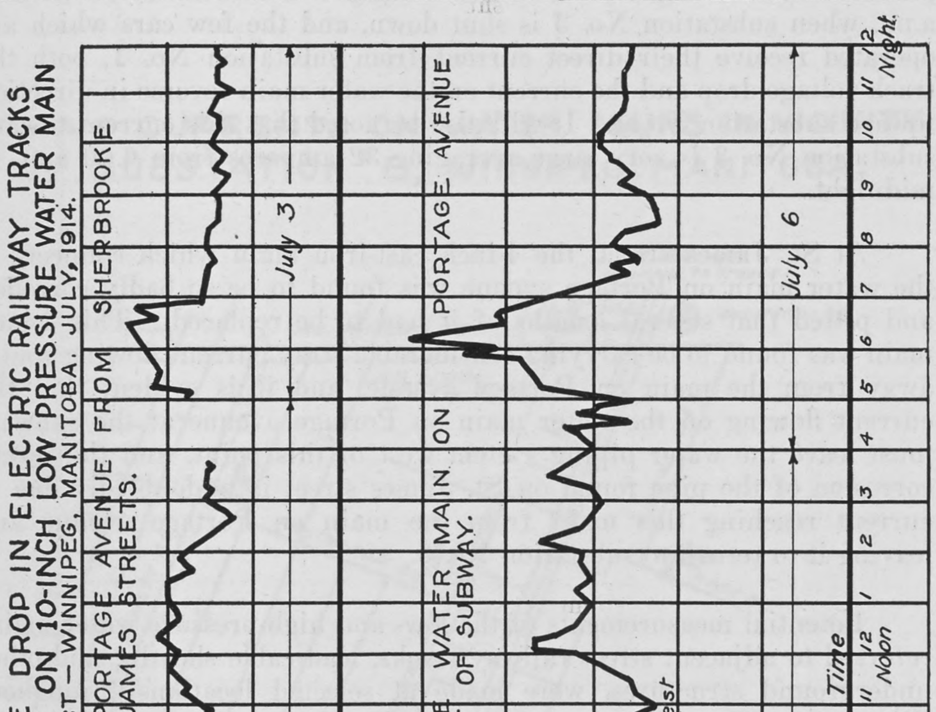


Fig. 5

and a 24-hour record of voltage drop in the electric railway tracks on Portage avenue, from Sherbrooke street to St. James street are shown. While these two records were not obtained simul-

taneously, they nevertheless represent normal operating conditions, and the agreement of the characteristic variations in the current on the water main and the track voltage drop is so close, that it is conclusive evidence that the current on the water main is caused by the voltage drop in the tracks on Portage avenue paralleling this main. It is particularly striking that during the night hours from 12.30 to 5.30 a.m., when substation No. 3 is shut down, and the few cars which are operated receive their direct current from substation No. 1, both the track voltage drop and the current on the water main reverse in direction toward substation No. 1. It will also be noted that this current toward substation No. 3 is very large averaging 32 amperes from 6.00 a.m. to midnight.

At St. James street, the 4-inch cast-iron main which connects to the water main on Portage avenue was found to be so badly corroded and pitted that several lengths of it had to be replaced. This 4-inch main was found to be carrying considerable stray current flowing south, away from the main on Portage avenue, and it is evident that the current flowing on the water main on Portage avenue at the subway, must leave the water piping system west of this point, and the severe corrosion of the pipe found on St. James street is undoubtedly due to current reaching this main from the main on Portage avenue and leaving it to return to substation No. 3.

Potential measurements of the low- and high-pressure water mains referred to adjacent street railway tracks, lead cable sheaths, and other underground structures, were made at selected locations throughout Winnipeg. These locations were usually chosen so as to be in the immediate neighborhood of the railway substations and at the feeding limits of each substation. The maximum, minimum, and average values of the results of these potential measurements are given in table No. 5. It will be seen from this table that the water pipes are highly positive to the street railway tracks in the vicinity of each railway substation, while near the feeding limits of these stations they are generally highly negative in potential to the tracks.

It will also be noted from table No. 5 that the low- and high-pressure water mains were at practically the same potential at nearly all points tested. One exception to this was on McPhillips street, where the high-pressure water main was 1.1 volt average positive to the low-pressure water main. This low-pressure water main on McPhillips street is itself highly positive to the street railway tracks at Logan avenue in the neighborhood of substation No. 8, this positive potential averaging nearly 6 volts during peak load. There is, therefore, a strong tendency for current to leave the high-pressure main on McPhillips street to flow to the low-pressure main and to leave this latter main to return to substation No. 8 near Logan avenue. The layout of the low-pressure and high-pressure mains in the neighborhood of substation No. 8, together with the current on these mains and of their potential relations is shown in fig. 6. The fact that the high-pressure mains on

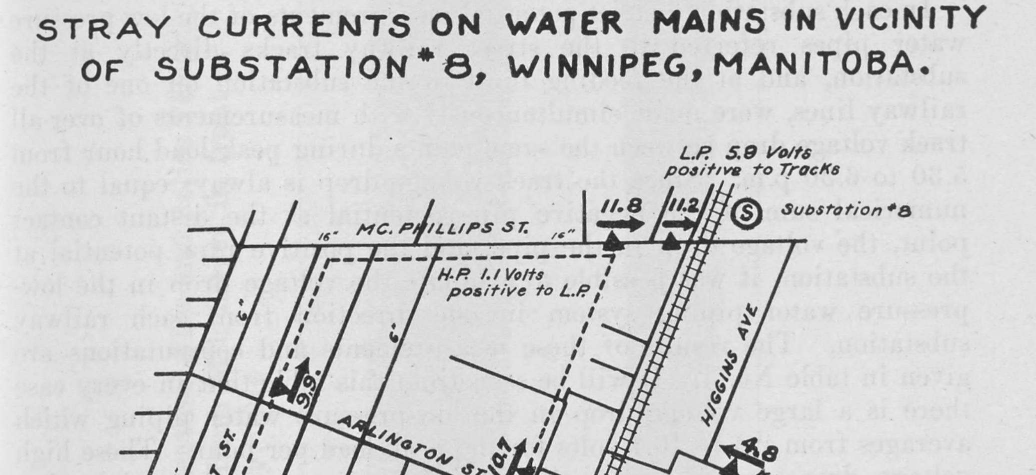

STRAY CURRENTS ON WATER MAINS IN VICINITY OF SUBSTATION # 8, WINNIPEG, MANITOBA.
L.P. 5.8 Volts positive to Tracks
11.8
11.2
Substation # 8
MC. PHILLIPS ST.
H.P. 1.1 Volts positive to L.P.
HIGGINS AVE
9.9
ARLINGTON ST.
10.7
4.8
KNOX ST.
MC. DERMOTT ST.
ALEXANDER AVE
LOGAN AVE
SHARBROOKE ST.
LEGEND
PERMANENT ELECTRICAL TEST STATIONS ON WATER MAINS
ARROWS WITH FIGURES DENOTE DIRECTION AND AVERAGE VALUES OF CURRENTS ON MAINS
LOW PRESSURE MAINS
HIGH PRESSURE MAINS

Fig. 6

Alexander avenue and on McDermot avenue, just east of McPhillips street, were found to carry large stray currents flowing towards McPhillips street, makes it quite evident that there is an actual flow of current from these high-pressure mains through earth to the low-pressure main in McPhillips street with consequent danger to the high-pressure mains from electrolysis. This current must again leave the low-pressure main near Logan avenue, so that it also endangers the low-pressure main in the neighborhood of substation No. 8.

In each substation district potential measurements of the low-pressure water pipes referred to the street railway tracks directly at the substation, and at the feeding limit of the substation on one of the railway lines, were made simultaneously with measurements of over-all track voltage drop between the same points during peak load hour from 5.30 to 6.30 p.m. Since the track voltage drop is always equal to the numerical sum of the negative pipe potential at the distant contact point, the voltage drop in the pipe, and the positive pipe potential at the substation, it was possible to compute the voltage drop in the low-pressure water piping system in one direction from each railway substation. The results of these measurements and computations are given in table No. 4. It will be seen from this table that in every case there is a large voltage drop in the low-pressure water piping which averages from 2.4 to 10.7 volts for the peak load per hour. These high voltage drops indicate that the water pipes carry substantial stray electric railway currents towards the respective substations.

TESTS RELATING TO UNDERGROUND CABLE SYSTEMS IN WINNIPEG.

There are four principal underground cable systems in Winnipeg as already described, and their layout is shown in plate No. 4. All of the underground cables except the telephone cables have been installed during the past few years. Electrical drainage had been applied sometime ago to the underground cables of the Winnipeg Electric Railway Company and of the Manitoba Government Telephone Commission in the district of substation No. 1, and also to the cable sheaths of the railway company near substation No. 3. At the Mill street substation a drainage connection had also been installed to the 2-inch Pintsch gas pipe which is laid along the transfer tracks near Lombard street. The locations and sizes of all of the drainage connections, together with the all-day average values of the currents drained from them, are given in table No. 9. It will be seen from this table that the total average current drained to the railway return conductors of substation No. 1 was 461 amperes. The normal all-day average load for this substation was 3320 amperes. The current returned over these cable drainage connections was therefore about 14 per cent. of the current output of the station. While no drainage connections had been installed from the city light and power cable sheaths, they were found to be partially drained through metallic contacts existing between all of the cable systems. The sheaths of the city fire and police telegraph cables were effectively drained through the bond connections to the telephone cable sheaths.

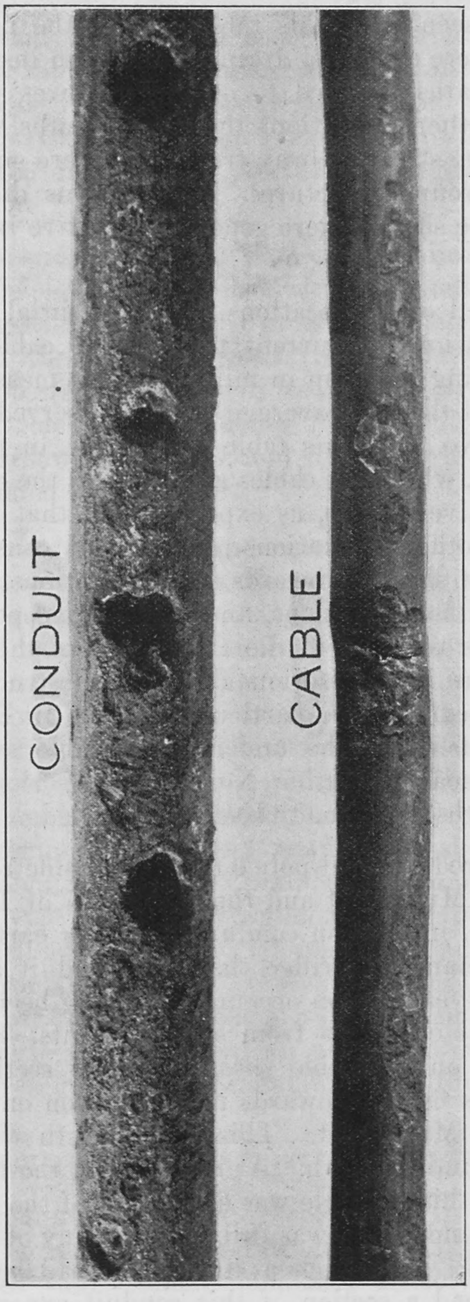


Fig. 7

Corroded and Pitted Iron Conduit and Lead Sheathed Fire and Police Telegraph Cable Contained in this Conduit Removed from Mill Street in front of Substation, July, 1914

Measurements of the potential of the various cable sheaths referred to each other, to adjacent water pipes, and to street railway tracks, were made at many characteristic locations in each of the substation districts. The maximum, minimum, and average values of these potential measurements are given in table No. 5.

It will be seen from this table that in the neighborhood of substation No. 1 where electrical drainage had been installed, the potentials of the cable sheaths referred to other structures were relatively low, while near the other substations the cable sheaths were highly positive in potential to the street railway tracks and were generally also positive to other underground structures. At locations distant from the substations, the cable sheaths were generally negative in potential to trolley tracks.

At nearly all of the locations where potential measurements were made, determinations of current flow on the cable sheaths were also made by measuring the drop in millivolts in a measured length of each cable sheath, and the total average current observed in each manhole is given in table No. 8. This table shows that in the neighborhood of substation No. 1, where the cables are drained, the currents on the cable sheaths are relatively large, as expected; but that in the neighborhood of each of the other substations, currents of considerable magnitude also flow on the sheaths towards the substations. The flow of this current towards the substations, and the positive potential condition of the cable sheaths referred to the trolley tracks there, show that these cable sheaths were in very serious danger of destruction by electrolysis. This danger appeared to be particularly acute in Portage avenue near Strathcona street where the underground cable system ends, and in Osborne street, near substation No. 2, where serious corrosion of telephone cable sheaths has already been experienced.

A lead covered fire and police telegraph cable runs from a manhole at the corner of Mill street and the lane south of Lombard street, into substation No. 1, in an iron conduit buried in earth. I was informed by City Electrician Cambridge that this conduit and cable had been renewed about a year ago on account of having been destroyed by what he believed was electrolysis from stray currents. I therefore made a number of tests on the cable sheaths in this section and found that stray current was flowing towards the substation on the cable sheath in this manhole on Mill street. This cable sheath was also found to be positive to surrounding earth. At my request, the length of cable from the substation to this manhole was drawn out of the conduit for examination. It was found that it was full of pits, many of which were entirely through the lead. Inasmuch as this cable had been laid in an iron conduit, I also had a section of this conduit exposed, and found that this conduit was also badly pitted and was full of holes. The conduit was found to be 1.5 volts positive in potential to surrounding earth. In fig. 7 a photograph of corresponding sections of this conduit and cable sheath is reproduced. It is evident that this corrosion and pitting which has destroyed the conduit and cable sheath has been caused by

electrolysis from stray currents leaving the cable sheath and conduit for earth. This electrolytic destruction has developed in spite of the fact that the fire and police telegraph cable sheaths through their bond connections to the telephone cable sheaths, were electrically drained at the main telephone exchange, which is only a few blocks from the point where they were destroyed. The reason for this electrolytic destruction in Mill street was that the negative busbar was grounded through gas and water piping in the station, causing the earth in the neighborhood of the substation to be very much lower in potential than the earth at the corner of Main street and Portage avenue, where the nearest trolley tracks are located, the difference in potential averaging about 6.0 volts during peak load.

The only safe and permanent plan for minimizing the present danger to these cable sheaths from electrolysis, as well as from possible fires and other dangers which may be produced by stray currents, is to remove as much of the return current from the tracks by adequate return feeders as possible. This will reduce the track voltage drop which will of itself remove the tendency for current to shunt through earth and on underground structures, and such electric railway improvements are recommended in this report.

The danger of destruction of underground cables from electrolysis appeared so serious to me, however, that I did not consider it safe to allow the cables to remain in their dangerous condition until railway improvements could be made, and for this reason, with the approval of your Commission, I had installed under my personal direction temporary electrical drainage connections from the cable sheaths to railway return conductors in each of the substation districts, in order to afford protection to the lead covered cables. The results of the detailed investigation made on the cable sheaths, both to determine their electrolytic condition and where proper temporary drainage connections should be installed, have already been submitted to your Commission in a preliminary report dated November 17, 1914. In my opinion these temporary connections must be retained until adequate provision has been made to eliminate the excessive stray currents in earth at present existing in Winnipeg. I have added a copy of this preliminary report as an Appendix to the present report, because I believe that all of the information contained therein should be presented in permanent form for future reference.

DISCUSSION OF APPLICATIONS AND BRIEFS FILED WITH COMMISSION.

Most of the claims and requests contained in the applications, briefs, reports and correspondence relating to this investigation, which have been filed with your Commission, have already been covered in previous parts of the report and need therefore not be considered again. The important points which have not been considered before are briefly discussed in the following.

The city states in its application: "The system of using ground plates at sides of bridges for carrying return currents from one side

of a river bank to the other is bad." I have made examinations at points where such ground plates would be expected but have failed to find any, and the railway company informs me that such ground plates have been removed wherever they were known to exist.

The question of proper bonding, etc., at bridges has also been raised by the city. I have made examinations and tests at the principal bridges in Winnipeg over which electric railway lines pass, but have not found any abnormal conditions. The track voltage drop limitations recommended in this report will take care of any such abnormal conditions as may exist or develop in the future.

The city, in its brief, requests "that a standard be prescribed wherein the maximum difference of potential between any two points on the return circuits of the Winnipeg Electric Railway system 1,000 feet apart shall not exceed the limit of 0.3 volt during the average schedule traffic and that the maximum over-all voltage drop within the city limits shall not exceed the limit of over 7 volts." A 7-volt over-all limit is contained in the British Board of Trade regulations and is included in my recommendations. A requirement of 0.3 volt in 1000 feet is in my opinion unnecessarily severe. The British Board of Trade regulations prescribe a limit for the current density in the rails, which with ordinary steel rail is equivalent to a voltage gradient limit in the tracks of about 0.8 volt in 1000 feet. I have used a limit of 1.0 volt in 1000 feet in my recommendations, as *this in my opinion sufficiently meets the present requirements in Winnipeg.*

The city, in its brief, requests "that a standard be set for the maximum allowable limits of stray currents in foreign underground structures". No one standard could be set that would insure the same degree of immunity to structures of different materials and subjected to different conditions, so that it would be necessary to have a graded set of standards. In my opinion this is entirely impracticable, and when suitable track voltage limitations are imposed this is also unnecessary.

The city requests "that the operation of each street railway substation be continuous during the schedule hours of operation of cars"; and also "that a direction be made as to the tying in of the various substations to each other." These requirements are, in my opinion, unnecessary, if the track voltage limitations contained in the recommendations are properly complied with.

The city requests "that at the east end of the Bannerman avenue track there should be a direct connection between such track and the rails of the Main street system". This connection has already been made by the railway company, and a condition of this kind would be covered by the track voltage requirements contained in my recommendations.

In a supplemental letter from the city, complaint is made that when the ground is opened in the vicinity of gas mains there seems to

be a large escape of gas, and the question is raised whether this is due to electrolysis. It is also stated that gas is now found in a number of the underground conduit systems, including that of the Manitoba Government Telephone system. In a later letter, also filed with the Commission, it is stated that illuminating gas was found in the manholes at Sutherland avenue and Main street, Disraeli street and Rover avenue, and Rachael street and Rover avenue. I inspected each of these three manholes personally but failed to find evidences of gas leakage. When the high-pressure water main at the corner of Portage avenue and Main street was exposed, there was, however, a strong smell of gas in this excavation, and the gas main which was exposed here was found to be graphitized so that pits could be dug out. When the surface of the main was scraped there was a strong smell of gas at the surface, indicating that the gas was seeping through the pipe. This condition of the gas main has undoubtedly been caused by electrolysis. I did not have an opportunity to examine other gas mains owing to the lack of time and the difficulties of making excavations in Winnipeg. Unquestionably, however, such corrosion of gas mains by electrolysis has taken place in many parts of Winnipeg. At my suggestion, Mr. Hugh McNair, gas engineer of the Commission, examined gas mains at several points where smell of gas was reported, and I quote below his report on these examinations:

> I examined the gas mains at the corners of Stanley and Logan, Main and Portage, Main and James, Donald and Graham, in order to determine whether the leak of gas were due to electrolysis or not. The leak at Stanley and Logan was due to defective workmanship. The main was perfectly sound, and showed no traces of electrolysis, and in fact none of the mains, with the exception of that on Main street, showed any signs of electrolysis. The one on Main street which you saw yourself showed unmistakable signs of electrolysis, and was, in my opinion, in very bad condition. The main in Portage avenue was comparatively new, and need not be taken into consideration so far as showing the effects of electrolysis, as the main mentioned has only been down for about six months.
>
> HUGH MCNAIR,
> Gas Engineer.
>
> Winnipeg, Man., October 28th, 1914.

The brief of the Manitoba Government Telephone Commission states that the street railway company should be compelled to carry all of the current which it produces back to the power station on its own copper cables and that nothing short of this will ever be satisfactory to the water, gas and telephone interests. This request would require a change in the railway system to a double trolley or other system in which the electric circuit is completely insulated from earth. In my opinion the conditions in Winnipeg do not warrant such a radical remedy. This brief asks that an expert decide the permissible difference of potential between the telephone cables and earth, and the maximum current in amperes that any telephone cable sheath of given size should be permitted to carry. It is not practicable to specify these limits.

In the brief of the Winnipeg Electric Railway Company the claim is made that the voltage drop in the tracks in Winnipeg is well within the British Board of Trade regulations. As already explained, the actual track voltage drop was, however, found to be greatly in excess of

the 7-volt limit required by these regulations. From conferences with the officials of the railway company, I judge that the statement in the brief was made because they did not correctly understand these Board of Trade regulations.

The railway company, referring in its brief to a letter written by me and appearing in the Electric Railway Journal for April 25, 1914, states "our system of negative returns and checking up of the drop in the rails has been practically along the lines as laid down by Professor Ganz in this letter". This statement is based on a misunderstanding of my letter, because all of the negative return cables installed on the Winnipeg Electric Railway system, while themselves covered by insulation, are in effect conductors in parallel with the tracks, since at every substation the negative busbar is directly connected to the tracks nearest it. In the letter referred to, I specified the use of the insulated return feeder system, which requires the negative busbar at the station being connected to the tracks only through a suitable resistance.

In this brief it is also stated "some years ago the city electrician and city authorities insisted that no other system of bonding be used except the brazed bonds, which from experience we have found to be a very difficult and expensive one to maintain. Some parts of the system which were bonded with other types of bond have been found to show equally as well or better results and no troubles or annoyances with renewals, due to broken bonds, etc." A short brazed bond as used in Winnipeg, when first installed, and so long as it is in good condition, affords a satisfactory and low-resistance connection across rail joints, but with vibration, such brazed bonds are likely to become broken. They are also very liable to mechanical injury because of their location on the side of the rail head, where wagon wheels and other traffic break them off. It is my opinion that for most of the tracks in Winnipeg, a concealed type of bond is preferable to the brazed bond, but I also believe that no particular type of bond should be prescribed, the railway company being permitted to use its own discretion in the selection of rail bonds so long as the required standard of rail joint resistance is maintained, and the track voltage drop requirements are met.

The railway company also states in its brief that it owns a large gas piping system in Winnipeg, and so far no gas leaks due to electrolysis have been found. From this it draws the conclusion that if there was any extensive damage to underground structures, the gas mains would also be affected to some extent. However, the absence of leaks is no proof that the gas pipes have not been corroded by electrolysis, and it certainly is no proof that other underground structures, such as water mains and lead cable sheaths, have not been affected by electrolysis. Water mains are usually much more affected by stray currents in earth than are gas mains, because there is generally slight leakage of water at joints which maintains the soil around the pipe damp and of higher electrical conductivity, while lead cable sheaths are many times more sensitive to electrolysis than cast-iron pipes, and are therefore much more quickly affected than cast-iron pipes.

The only reliable method of determining whether or not a cast-iron main has been damaged by electrolysis is to expose it at many points and examine it closely, using a knife or a test hammer to remove the graphitic material which is always formed when cast-iron is corroded by electrolysis, and which remains in place and maintains the pipe gas tight and often water tight so long as the main is not disturbed. This is especially true where the pipes are laid in a clay soil like that found in Winnipeg, and is well illustrated by the gas main exposed at Portage avenue and Main street, and also by the water mains exposed in St. James street at Portage avenue, in Osborne street at Morley avenue, and in Fort street at Portage avenue. In these cases the mains which were exposed for other repairs were found when examined to be very badly corroded and pitted, although no leak or other outward sign of the damage had developed.

TABLE NO. 1

Current Ratings and Average Currents Delivered from Railway Substations of the Winnipeg Electric Railway Company — Winnipeg, Manitoba

Number of Substation and Location	Date Station was Started	Rating in Amperes		Average Currents Delivered on Normal Day of Operation			Average Voltage During Peak Hour June 24, 1914
		Normal	One Hour Overload	Between 6.00 a.m. and Midnight June 25, 1914	For Peak Hour 5.30 p.m. to 6.30 p.m. June 24, 1914	For Highest Ten Minutes During Peak Hour June 24, 1914	
Substation No. 1: Mill street at Red River	June 11, 1906	7560	11340	3320	5104	6103	582
Substation No. 2: Osborne street at Kylemore avenue	Sept. 5, 1909	1665	2490	880	1108	1280	560
Substation No. 3: Portage avenue at St. James street	Oct. 14, 1909	3665	5490	1500	2136	2765	598
Substation No. 4: Main street at Inkster avenue	Dec. 29, 1909	1390	2085	1020	1252	1510	541
Substation No. 8: Logan avenue at McPhillips street	Nov. 18, 1912	2000	3000	935	1213	1464	555
Substation No. 10: Assiniboine avenue at Garry street	Sept. 25, 1912	2333	3500	1625	1978	2255	565

TABLE NO. 2

Overall Voltage Measurements in Street Railway Tracks—Winnipeg, Manitoba
Negative Contact at Point of Lowest Potential in Tracks for Each Substation District

Date	Number and Location of Substation Location of Positive Contract	Maximum Momentary Voltage	Period of Test Hours	Average Volts: For Peak Load Hour 5.30 to 6.30 p.m.	Average Volts: For Highest Ten Minutes During Peak Load Hour	Average Volts: For Total Period of Operation During Day
	Substation No. 1—Mill street at River:					
6/29/14	(a) Portage avenue at Sherbrooke street	14.0	24	9.5	11.5	5.5
6/29/14	(a) Logan avenue at Sherbrooke street	11.5	1½	6.8	7.2	....
6/29/14	(a) Selkirk avenue at McGregor street	21.0	1½	12.4	13.9	....
6/29/14	(a) Louise Bridge	18.5	1½	13.6	15.1	....
6/29/14	(a) Provencher avenue at Des Meurons street, St. Boniface	15+	1½	8.5	10.3	....
7/3/14	(a) Main street at Flora avenue	19.0	1½	12.7	15.3	....
10/23/14	(a) Main street at Flora avenue	19.0	1	15.3	16.4	....
7/3/14	(a) Notre Dame avenue at west end of car line	20.0	1½	14.3	16.1	....
6/29/14	(b) Tracks at Portage avenue and Main street to negative busbar (grounded)	6.9	1½	5.6	6.1	....
	Substation No. 2—Osborne street at Kylemore avenue:					
6/25/14	Godfrey avenue at end of car line at Ash street	17.5	18	11.5	12.0	9.9
6/25/14	Jubilee avenue at city limit	12.4	1	5.0	6.9	....
7/3/14	Osborne street at Corydon avenue	10.5	1½	7.0	8.1	....
	Substation No. 3—Portage avenue at St. James street:					
6/24/14	Sargent avenue at McGee street	30.0	23	20.8	22.0	16.3
7/3/14	Portage avenue at Sherbrooke street	32.0	23	23.5	26.0	17.0
	Substation No. 4—Main street at Insker avenue:					
7/2/14	Selkirk avenue at McGregor street	23.5	23	9.1	11.0	6.3
7/2/14	Talbot avenue at Mt. Calm	16.5	1½	9.3	10.9	....
7/2/14	Kelvin street at North city limit	20.5	1½	12.5	14.1	....
	Substation No. 8—Logan avenue at McPhillips street:					
6/26/14	Selkirk avenue at McGregor street	25+	24	17.8	20.0	10.8
6/26/14	Logan avenue at Sherbrooke street	15+	1	11.3	12.5	....
6/26/14	Logan avenue at Blake street	8.5	2	2.9	3.9	....
6/26/14	Notre Dame avenue at Arlington street	21.5	2	15.0	16.9	....
	Substation No. 10—Assiniboine avenue at Garry street:					
6/30/14	Osborne street at Corydon avenue	13.5	1½	10.4	12.0	....
6/30/14	Sherbrooke street at Cornish avenue	18.5	1½	13.5	15.2	....
6/30/14	St. Mary's road at Kingston row, St. Vital, end of car line	20.4	1½	11.4	14.3	....
6/30/14	Portage avenue at Sherbrooke street	14.2	1½	10.4	12.7	....

(a) These voltage measurements refer to tracks at corner of Portage avenue and Main street. The tracks at this point are however 5 to 6 volts positive to negative busbar, as is shown at (b), and as this busbar is grounded at the substation, the values in (b) should be added to those under (a) to give true overall potentials affecting underground structures.

TABLE NO. 3

Comparison of Measured and Computed Overall Voltage Drop in Street Railway Tracks—Winnipeg, Manitoba

Average Values for Peak-Load Hour, 5.30-6.30 p.m.

Number and Location of Substation: Location of Positive Contact	Highest 10-Minute Average Values During Peak Hour	
	Measured	Computed
Substation No. 1—Mill street at River:		
Portage avenue at Sherbrooke street	11.5	13.5
Logan avenue at Sherbrooke street	7.2	14.0
Selkirk avenue at McGregor street	13.9	21.0
Louise Bridge	15.1	23.5
Provencher avenue at Des Meurons street, St. Boniface	10.3	20.5
Main street at Flora avenue	15.3	21.0
Notre Dame avenue at west end of car line	16.1	17.5
Substation No. 2—Osborne street at Kylemore avenue:		
Godfrey avenue at end of car line at Ash street	12.0	22.0
Jubilee avenue at city limit	6.9	6.5
Osborne street at Corydon avenue	8.1	11.5
Substation No. 3—Portage avenue at St. James street:		
Sargent avenue at McGee street	22.0	43.5
Portage avenue at Sherbrooke street	26.0	44.0
Substation No. 4—Main street at Inkster avenue:		
Selkirk avenue at McGregor street	11.0	17.0
Talbot avenue at Mt. Calm	10.9	23.0
Kelvin street at North City limit	14.1	23.0
Substation No. 8—Logan avenue at McPhillips street:		
Selkirk avenue at McGregor street	20.0	13.0
Logan avenue at Sherbrooke street	12.5	6.0
Logan avenue at Blake street	3.9	6.0
Notre Dame avenue at Arlington street	16.9	7.0
Substation No. 10—Assiniboine avenue at Garry street:		
Osborne street at Corydon avenue	12.0	15.0
Sherbrooke street at Cornish avenue	15.2	25.0
St. Mary's Road at Kingston Row, St. Vital, end of car line	14.3	24.5
Portage avenue at Sherbrooke street	12.7	18.0

TABLE NO. 4

Potentials between Low-pressure Water Pipes and Street Railway Tracks, Measured Simultaneously with Overall Voltage Drop in Tracks, and Overall Voltage Drop in Water Pipes Computed from these Measured Potentials

Average Values for Peak-Load Hour, 5.30 to 6.30 p.m., Winnipeg, Manitoba

Date	Location	Measured Potential of Water Pipe Referred to Tracks Volts	Measured Overall Voltage Drop in Tracks Volts	Computed Overall Voltage Drop in Water Pipes Volts
	District of Substation No. 1, Mill street at River			
10/23/14	Main street at Portage avenue	+0.4		
	Main street at Flora avenue.	−4.2	15.3	10.7
	District of Substation No. 2, Osborne street at Kylemore avenue			
6/25/14	At substation........	+3.2	....	....
	Jubilee avenue near City Limit........	+2.2 −1.5	5.0	2.4
	Godfrey avenue at Ash street, west end of car line.......	−5.4	11.5	2.9
	District of Substation No. 3, Portage avenue at St. James street.			
6/24/14	At substation........	+9.6	....	....
	Sargent avenue at McGee street........	−2.0	20.8	9.2
	District of Substation No. 4, Main street at Inkster avenue.			
7/2/14	At substation........	+2.3	....	....
	Selkirk avenue at McGregor street........	−2.3	9.1	4.5
	District of Substation No. 8, Logan avenue at McPhillips street.			
6/26/14	At substation........	+5.9	....	....
	Notre Dame avenue at Arlington street........	−4.7	15.0	4.4
	District of Substation No. 10, Assiniboine avenue at Garry street.			
6/30/14	At substation........	+1.0	....	....
	Sherbrooke street at Cornish avenue........	−3.8	13.5	8.7

TABLE NO. 5

Potential Measurements of Various Underground Pipes and Cable Sheaths referred to each other and referred to Street Railway Tracks, Winnipeg, Manitoba

Date and Time	Location and Structures Tested	Duration of test Minutes	Potential Volts Max.	Min.	Ave.
7/14/14	**Albert street at lane north of Notre Dame avenue.**				
11.30 a.m.	City Light and Power cables to Street Railway cables......	2	+2.7	+2.3	+2.5
	Alexander avenue east of Stanley street.				
	H.P. water pipe to gas pipe....	2	....	....	+0.1
10/29/14	**Assiniboine avenue at Garry street.**				
2.55 p.m.	City Light and Power (arc light) cable to Street Railway return feeder cables in duct crossing first cable..........	5	+3.7	+2.9	+3.5
10/28/14 12.32 p.m.	City Light and Power (arc light) cable to Street Railway return feeder cables in duct crossing first cable..........	5	+4.0	+3.3	+3.6
12.27 p.m.	City Light and Power (arc light) cable to L.P. water pipe..........................	5	+3.6	+2.8	+3.2
..	L.P. water pipe to railway return feeder cable..........	..	....	....	*+0.4
7/14/14	**Broadway at Carlton street**				
11.00 a.m.	City Light and Power cables to L.P. water pipe............	2	+0.6	+0.4	+0.5
11.02 a.m.	City Light and Power cables to tracks..................	2	+2.0	+0.6	+1.0
..	L.P. water pipe to tracks......	..	....	....	*+0.5
10/31/14	**Charlotte street at McDermot avenue.**				
10.00 a.m.	Manitoba Government Telephone cables to L.P. water pipe.......................	3	−0.4	−0.3	−0.35
11.03 a.m.	Manitoba Government Telephone cables to H.P. water pipe.......................	3	−1.1	−0.8	−1.0
..	H.P. water pipe to L.P. water pipe.......................	..	....	....	*+0.65
6/25/14	**Godfrey avenue at Ash street, west end of car line.**				
5.30 p.m.	L.P. water pipe to tracks......	60	−8.7	−3.2	−5.4
7/14/14	**Higgins avenue at McPhillips street.**				
10.00 a.m.	City Light and Power cables to L.P. water pipe..........	2	+1.9	+1.1	+1.3
10.02 a.m.	City Light and Power cables				
10.02 a.m.	City Light and Power cables to tracks..................	2	+4.7	+2.5	+3.7
..	L.P. water pipe to tracks......	..	....	....	*+2.5
10/27/14 5.00 p.m.	City Light and Power cables to tracks..................	5	+5.0	+2.0	+4.0

*Computed Values

TABLE NO. 5 (A)

Potential Measurements of Various Underground Pipes and Cable Sheaths referred to each other and referred to Street Railway Tracks, Winnipeg, Manitoba

Date and Time	Location and Structures Tested	Duration of test Minutes	Potential Volts Max.	Potential Volts Min.	Potential Volts Ave.
7/14/14	**Higgins avenue at Princess street.**				
2.30 p.m.	City Light and Power cables to L.P. water pipe..........	2	−1.1	−0.9	−1.0
2.32 p.m.	City Light and Power cables to Fire and Police Telephone cables....................	2	+0.4	+0.2	+0.3
6/25/14	**Jubilee avenue near City Limit.**				
5.30 p.m.	L.P. water pipe to tracks......	35	+7.0	0	+2.2
		25	−4.0	0	−1.5
8/18/14	**Kelvin street near Harbison avenue. (At dividing line between Elmwood and East Kildonan)**				
..	L.P. water pipe to tracks......	2	−7.0	−3.5	−5.0
7/14/14	**King street at Henry avenue .**				
..	L.P. water pipe to H.P. water pipe......................	2	....	....	+0.07
10/30/14	**King street at Higgins avenue.**				
	City Light and Power cables to tracks..................	2	−4.0	−1.9	−2.5
During Morning	City Light and Power cables to L.P. water pipe..........	2	−0.6	−0.5	−0.5
	City Light and Power cables to H.P. water pipe.........	2	−0.9	−0.7	−0.8
	L.P. water pipe to tracks......	..	....	....	*−2.0
..	H.P. water pipe to L.P. water pipe.....................	..	....	....	*+0.3
11/ 5/14					
4.05 p.m.	City Light and Power cables to tracks..................	3	−3.3	−2.0	−2.6
4.09 p.m.	City Light and Power cables to L.P. water pipe..........	3	−1.0	−0.6	−0.8
4.09 p.m.	City Light and Power cables to H.P. water pipe.........	3	−1.3	−0.8	−1.0
..	H.P. water pipe to L.P. water pipe.....................	..	....	....	*+0.2
4.12 p.m.	L.P. water pipe to tracks......	3	−2.5	−1.4	−1.8
4.12 p.m.	H.P. water pipe to tracks.....	3	−2.2	−1.0	−1.6
..	H.P. water pipe to L.P. water pipe.....................	..	....	....	*+0.2
11/ 2/14	**King street north of Notre Dame avenue at City Light and Power Substation.**				
4.30 p.m.	City Light and Power cables to L.P. water pipe.........	3	+0.02	−0.02	....
	*Computed Values.				

TABLE NO. 5 (B)

Potential Measurements of Various Underground Pipes and Cable Sheaths referred to each other and referred to Street Railway Tracks, Winnipeg, Manitoba

Date and Time	Location and Structures Tested	Duration of test Minutes	Potential Volts		
			Max.	Min.	Ave.
10/31/14	**Lane north of Portage avenue, west of Carlton street.**				
11.25 a.m.	Manitoba Government Telephone cables to Street Railway cables (duct lines run close together)	5	+0.9	+0.7	+0.8
8/18/14	**Logan avenue at East street.**				
..	L.P. water pipe to tracks	2	+4.2	+1.5	+2.8
6/26/14	**Logan avenue at McPhillips street.**				
5.30 p.m.	L.P. water pipe to tracks	60	+7.6	+3.0	+5.9
10/30/14	**Main street at Alexander avenue**				
	City Light and Power cables to tracks	2	−2.6	−2.0	−2.3
During Morning	City Light and Power cables to L.P. water pipe	2	−0.1	−0.07	−0.09
	City Light and Power cables to Manitoba Government Telephone cables	2	+0.21	+0.15	+0.17
..	L.P. water pipe to tracks	..	....	....	*−2.1
6/30/14	**Main street at Assiniboine avenue.**				
5.30 p.m.	L.P. water pipe to tracks	60	+1.4	+0.9	+1.0
11/5/14	**Main street at Athol avenue.**				
4.48 p.m.	Manitoba Government Telephone cables to tracks	5	+5.0	+1.0	+3.2
4.48 p.m.	Manitoba Government Telephone cables to L.P. water pipe	5	+1.2	+0.7	+0.9
..	L.P. water pipe to tracks	..	....	....	*+2.3
7/22/14	**Main street Bridge.**				
3.00 p.m.	North end, Manitoba Government Telephone cables to tracks (at car barns)	2	+2.0	+1.0	+1.5
3.02 p.m.	South end, Manitoba Government Telephone cables to tracks	2	+1.2	+0.5	+1.0
10/23/14	**Main street at Flora avenue.**				
5.30 p.m.	L.P. water pipe to tracks	30	−5.5	−3.0	−4.2
7/22/14	**Main street at Higgins avenue.**				
10.00 a.m.	Manitoba Government Telephone cables to L.P. water pipe	2	−0.5	−0.4	−0.45
10.02 a.m.	Manitoba Government Telephone cables to track	2	−2.5	−1.5	−2.0

*Computed Values.

TABLE NO. 5 (C)

Potential Measurements of Various Underground Pipes and Cable Sheaths Referred to Each Other and Referred to Street Railway Tracks, Winnipeg, Manitoba

Date and Time	Location and Structures Tested	Duration of test Minutes	Potential Volts Max.	Min.	Ave.
10/30/14	**Main street at Higgins avenue.**				
During Morning	City Light and Power cables to tracks	2	−3.3	−2.3	−2.8
	City Light and Power cables to L.P. water pipe	2	−0.6	−0.4	−0.5
	City Light and Power cables to Manitoba Government Telephone cables	2	−0.15	−0.08	−0.12
..	L.P. water pipe to tracks	..	....	....	*−2.3
7/ 2/14 5.30 p.m.	**Main street at Inkster avenue.** L.P. water pipe to Street railway tracks	60	−4.0	+0.6	+2.3
7/22/14	**Main street at Market street.**				
During Morning	Manitoba Government Telephone cables to tracks	2	−1.5	−1.0	−1.2
	Manitoba Government Telephone cables to L.P. water pipe	2	....	....	−0.2
	Manitoba Government Telephone cables to City Light and Power cables	2	....	....	−0.3
..	L.P. water pipe to tracks	..	....	....	*−1.0
10/30/14	City Light and Power cables to tracks	2	−1.7	−1.3	−1.5
During Morning	City Light and Power cables to L.P. water pipe	2	+0.04	+0.03	+0.03
	City Light and Power cables to Manitoba Government Telephone cables	2	+0.4	+0.3	+0.35
...	L.P. water pipe to tracks	..	....	....	*−1.5
7/14/14	**Main street at McDermot avenue.**				
During Morning	City Light and Power cables to tracks	2	+0.35	−0.15	+0.05
	City Light and Power cables to H.P. water pipe	2	+0.35	+0.25	+0.3
	City Light and Power cables to Fire and Police Telephone cables	2	+0.2	+0.18	+0.19
	City Light and Power cables to L.P. water pipe	2	+0.16	+0.14	+0.15
11/ 2/14 4.40 p.m.	H.P. water pipe to tracks	10	−0.3	−0.02	−0.06
4.40 p.m.	Manitoba Government Telephone cables to tracks	10	+0.1	−0.2	....
4.40 p.m.	City Light and Power cables to tracks	10	+0.4	0	+0.2
4.50 p.m.	Manitoba Government Telephone cables to old Bell Telephone cables	5	+0.3	0	+0.2
4.55 p.m.	L.P. water pipe to H.P. water pipe	5	+0.3	+0.2	+0.2

*Computed Values.

TABLE NO. 5 (D)

Potential Measurements of Various Underground Pipes and Cable Sheaths Referred to Each Other and Referred to Street Railway Tracks Winnipeg, Manitoba

Date and Time	Location and Structure Tested	Duration of Test Minutes	Potential Volts Max.	Potential Volts Min.	Potential Volts Ave.
8/18/14	**Main street at Stella avenue.**				
9.30 a.m.	Manitoba Government Telephone cables to tracks.......	2	−3.2	−2.6	−3.0
10/30/14	**Main street at Sutherland avenue.**				
	City Light and Power cables to tracks................	2	−5.0	−3.0	−4.0
During Morning	City Light and Power cables to L.P. water pipe.........	2	−0.7	−0.5	−0.6
	City Light and Power cables to Manitoba Government Telephone cables..........	2	−0.6	−0.5	−0.55
..	L.P. water pipe to tracks.....	..	....	....	*−3.4
7/22/14	**Main street at York avenue.**				
3.00 p.m.	Manitoba Government Telephone cables to L.P. water pipe.....................	2	−0.4	−0.1	−0.2
3.02 p.m.	Manitoba Government Telephone cables to tracks.....	2	+0.8	+0.5	+0.7
..	L.P. water pipe to tracks.....	..	....	....	*+0.9
7/22/14	**Market street at Princess street**				
3.30 p.m.	Manitoba Government Telephone cables to L.P. water pipe.....................	2	−1.0	−0.7	−0.8
3.32 p.m.	Manitoba Government Telephone cables to tracks.....	2	−2.5	−2.0	−2.2
..	L.P. water pipe to tracks.....	..	....	....	*−1.4
8/18/14	**Montcalm street at Desalaberry avenue, Elmwood.**				
..	L.P. water pipe to tracks.....	2	−3.9	−1.8	−2.2
7/ 9/14	**McPhillips street at Pacific avenue.**				
6.00 p.m.	H.P. water pipe to L.P. water pipe.....................	5	....	....	+1.1
6/26/14	**Notre Dame avenue at Arlington street.**				
5.30 p.m.	L.P. water pipe to tracks.....	60	−10.6	−0.6	−4.7
7/14/14	**Notre Dame avenue at Ellice avenue.**				
11.00 a.m.	City Light and Power cables to tracks................	2	+0.8	0	+0.5
11.02 a.m.	City Light and Power cables to Fire and Police Telephone cables..................	2	....	....	−0.2
6/24/14	**Osborne street at Arnold avenue.**				
3.30 p.m.	Manitoba Government Telephone cables to tracks....	3	+4.0	+3.0	+3.5
3.33 p.m.	Manitoba Government Telephone cables to water in manhole..................	3	....	....	+1.0
3.36 p.m.	Water in manhole to tracks..	3	+3.0	+2.0	+2.5

*Computed Values.

TABLE NO. 5 (E)

Potential Measurements of Various Underground Pipes and Cable Sheaths Referred to Each Other and Referred to Street Railway Tracks, Winnipeg, Manitoba

Date and Time	Location and Structure Tested	Duration of test Minutes	Potential Volts Max.	Min.	Ave.
7/4/14	**Osborne street at Arnold avenue.**				
11.50 a.m.	Manitoba Government Telephone cables to tracks.....	2	+4.8	+1.5	+2.5
11.52 a.m.	Manitoba Government Telephone cables to L.P. water pipe.....................	2	+2.0	+0.5	+1.2
..	L.P. water pipe to tracks.....	..	....	....	*+1.3
7/23/14	Manitoba Government Telephone cables to L.P. water pipe.....................	2	+1.5	+0.5	+0.8
During Morning	Manitoba Government Telephone cables to tracks.....	2	+4.0	+1.5	+2.8
..	L.P. water pipe to tracks.....	..	....	....	*+2.0
7/4/14	**Osborne street at Corydon avenue.**				
	Manitoba Government Telephone cables to tracks.....	2	−1.5	−0.7	−1.2
During Morning	Manitoba Government Telephone cables to L.P. water pipe.....................	2	+0.4	+0.1	+0.2
..	L.P. water pipe to tracks.....	..	....	....	*−1.4
7/23/14 During Morning	Manitoba Government Telephone cables to L.P. water pipe.....................	2	+0.5	+0.2	+0.3
	Manitoba Government Telephone cables to tracks.....	2	−1.0	−0.5	−0.7
..	L.P. water pipe to tracks.....	..	....	....	*−1.0
6/24/14	**Osborne street at Kylemore avenue.**				
3.00 p.m.	Manitoba Government Telephone cables to tracks.....	3	+7.0	+5.0	+6.0
6/25/14 5.30 p.m.	L.P. water pipe to tracks.....	60	+5.5	+1.5	+3.2
7/23/14 10.00 a.m.	Manitoba Government Telephone cables to L.P. water pipe.....................	2	+1.2	+0.5	+0.9
10/26/14 4.40 p.m.	Manitoba Government Telephone cables to tracks.....	5	+6.0	+4.0	+5.0
10/27/14 11.01 a.m.	Manitoba Government Telephone cables to tracks.....	3	+4.3	+3.8	+4.0
10/24/14	**Osborne street at Morley avenue.**				
11.30 a.m.	L.P. water pipe to tracks.....	5	+4.0	+2.0	+3.0

*Computed Values.

TABLE NO. 5 (F)

Potential Measurements of Various Underground Pipes and Cable Sheaths Referred to Each Other and Referred to Street Railway Tracks, Winnipeg, Manitoba

Date and Time	Location and Structure Tested	Duration of test Minutes	Potential Volts Max.	Potential Volts Min.	Potential Volts Ave.
7/23/14	**Osborne street at River avenue.**				
During Morning	Manitoba Government Telephone cables to L.P. water pipe	2	−0.6	−0.2	−0.4
	Manitoba Government Telephone cables to tracks	2	−2.5	−0.9	−1.5
..	L.P. water pipe to tracks	..	....	....	*−1.1
10/30/14	**Osborne street at Scotland avenue.**				
5.40 p.m.	Manitoba Government Telephone cables to tracks	5	+2.5	+0.9	+1.4
7/ 6/14	**Portage avenue at Carlton street.**				
During Morning	Street Railway cables to tracks	5	−5.0	−3.0	−3.7
	Street Railway cables to L.P. water pipe	5	−2.3	−1.7	−2.0
	Street Railway cables to Fire and Police Telephone cables	5	−2.7	−2.3	−2.5
	Manitoba Government Telephone cables to Street Railway cables	5	+1.9	+1.6	+1.7
	Manitoba Government Telephone cables to L.P. water pipe	5	−0.4	−0.3	−0.35
	Manitoba Government Telephone cables to tracks	5	−2.2	−1.2	−1.8
11/ 3/14 5.01 p.m.	Manitoba Government Telephone cables to tracks	10	−3.6	−2.4	−2.6
5.01 p.m.	City Light and Power cables to tracks	10	−3.2	−2.1	−2.9
5.01 p.m.	Street Railway cables to tracks	10	−5.8	−4.0	−5.0
5.01 p.m.	L.P. water pipe to tracks	10	−2.9	−1.8	−2.3
..	Manitoba Government Telephone cables to Street Railway cables	..	....	....	*+2.4
..	City Light and Power cables to Street Railway cables	..	....	....	*+2.1
..	L.P. water pipe to Street Railway cables	..	....	....	*+2.7
10/29/14	**Portage avenue at Hargrave street.**				
2.50 p.m.	Street Railway cables to tracks	3	−3.8	−2.9	−3.4
2.53 p.m.	City Light and Power cables to Street Railway cables	3	+1.8	+1.3	+1.5
2.56 p.m.	City Light and Power cables to tracks	3	−2.9	−1.6	−2.3
2.59 p.m.	H.P. water pipe to Street Railway cables	3	+2.5	+1.5	+2.0
3.02 p.m.	H.P. water pipe to City Light and Power cables	3	+0.9	+0.5	+0.6
3.05 p.m.	H.P. water pipe to tracks	3	−1.9	−0.5	−1.0

*Computed Values.

TABLE NO. 5 (G)

Potential Measurements of Various Underground Pipes and Cable Sheaths Referred to Each Other and Referred to Street Railway Tracks Winnipeg, Manitoba.

Date and Time	Location and Structure Tested	Duration of test Minutes	Potential Volts Max.	Potential Volts Min.	Potential Volts Ave.
7/ 6/14	**Portage avenue at Home street.**				
9.30 a.m.	Street Railway cables to tracks	5	−6.0	−5.0	−5.5
9.35 a.m.	Street Railway cables to L.P. water pipe..................	5	−6.0	−5.0	−5.5
10/22/14	**Portage avenue at East Side of Main street.**				
..	L.P. water pipe to tracks....	60	+0.8	0	+0.4
10/23/14 5.30 p.m.	L.P. water pipe to tracks.....	60	+0.7	0	+0.4
10/26/14 3.15 p.m.	City Light and Power cables to Street Railway cables....	5	+2.8	+1.1	+2.0
3.30 p.m.	Manitoba Government Telephone cables to Street Railway cables...............	3	+0.8	+0.4	+0.7
3.45 p.m.	City Light and Power cables to Manitoba Government Telephone cables..........	3	+1.1	+0.5	+0.9
11/ 2/14 11.44 a.m.	Manitoba Government Telephone cables to tracks....	10	+0.5	+0.2	+0.4
11.44 a.m.	City Light and Power cables to tracks................	10	+1.4	+0.7	+1.0
11.44 a.m.	Street Railway cables to tracks	10	−1.0	−0.6	−0.8
11.44 a.m.	L.P. water pipe to tracks.....	10	+0.8	+0.4	+0.6
11.30 a.m.	H.P. water pipe to L.P. water pipe.....................	3	....	....	+0.05
10/23/14	**Portage avenue East at Main Telephone Exchange.**				
12.09 p.m.	Manitoba Government Telephone cables to Street Railway cables..............	12	+0.8	+0.3	+0.6
7/ 6/14	**Portage avenue at Pine street.**				
	Manitoba Government Telephone cables to tracks.....	5	+8.0	+4.0	+6.0
During Morning	Manitoba Government Telephone cables to L.P. water pipe......................	5	+6.0	+3.0	+5.0
	Manitoba Government Telephone cables to Street Railway cables...............	5	+11.0	+9.0	+10.0
..	L.P. water pipe to tracks.....	..	....	....	*+1.0
..	L.P. water pipe to Street Railway cables...............	..	....	....	*+5.0
	*Computed Values.				

TABLE NO. 5 (H)

Potential Measurements of Various Underground Pipes and Cable Sheaths Referred to Each Other and Referred to Street Railway Tracks Winnipeg, Manitoba.

Date and Time	Location and Structure Tested	Duration of test Minutes	Potential Volts		
			Max.	Min.	Ave.
10/24/14	**Portage avenue at Richmond street.** (One block east of St. James substation—R.R. manhole in which drainage cable connects to cable sheaths and runs in duct to negative bus—bar in substation.)				
4.30 p.m.	Street Railway cables to tracks	5	−1.2	−0.4	−0.7
6/27/14	**Portage avenue at St. James street.**				
10.00 a.m.	L.P. water pipe to tracks.....	3	+10.0	+6.0	+8.0
6/24/14					
5.30 p.m.	L.P. water pipe to tracks.....	60	+11.7	+6.8	+9.6
10/31/14					
1.55 p.m.	Manitoba Government Telephone Aerial cable to Street Railway cable............	5	+7.5	+5.0	+6.0
7/14/14	**Portage avenue at Smith street**				
12.00 Noon	City Light and Power cables to Street Railway cables....	2	+3.0	+2.6	+2.8
12.02 p.m.	City Light and Power cables to L.P. water pipe........	2	+0.3	+0.2	+0.25
12.04 p.m.	City Light and Power cables to tracks................	2	−0.7	−0.5	−0.6
11/2/14					
2.30 p.m.	H.P. water pipe to L.P. water pipe....................	3	....	....	+0.08
3.32 p.m.	Manitoba Government Telephone cables to tracks.....	15	−1.7	−0.3	−1.1
3.32 p.m.	City Light and Power cables to tracks................	15	−1.4	−0.1	−0.8
3.32 p.m.	Street Railway cables to tracks	15	−3.5	−1.6	−2.5
3.32 p.m.	L.P. water pipe to tracks.....	15	−1.4	−0.2	−0.8
..	Manitoba Government Telephone cables to Street Railway cables..............	..	....	....	*+1.4
..	City Light and Power cables to Street Railway cables....	..	....	....	*+1.7
..	L.P. water pipe to Street Railway cables...............	..	....	....	*+1.7
7/6/14	**Portage avenue at Strathcona street.**				
3.25 p.m.	Street Railway cables to tracks	5	−4.5	−2.5	−3.0
3.35 p.m.	L.P. water pipe to Street Railway cables...............	5	+11.5	+8.0	+9.0

*Computed Values.

TABLE NO. 5 (I)

Potential Measurements of Various Underground Pipes and Cable Sheaths Referred to Each Other and Referred to Street Railway Tracks Winnipeg, Manitoba

Date and Time	Location and Structure Tested	Duration of test Minutes	Potential Volts Max.	Min.	Ave.
10/24/14	**Portage avenue at Strathcona street.**				
3.45 p.m.	Street Railway cables to tracks	5	−6.0	−2.0	−3.5
3.55 p.m.	L.P. water pipe to Street Railway cables	5	+8.0	+3.0	+5.5
4.00 p.m.	Manitoba Government Telephone cables to Street Railway cables	5	+12.0	+5.0	+7.0
4.05 p.m.	L.P. water pipe to tracks	3	+3.0	+1.0	+2.0
4.08 p.m.	Manitoba Government Telephone cables to tracks	5	+6.0	+2.0	+3.0
10/27/14					
5.40 p.m.	L.P. water pipe to tracks	5	+3.1	+1.2	+2.3
11/ 3/14					
10.50 a.m.	Manitoba Government Telephone cables to tracks	5	+4.2	+2.4	+2.6
11.00 a.m.	Street Railway cables to tracks	5	−2.8	−1.1	−2.0
7/ 7/14	**Portage avenue East at Victoria street.**				
4.00 p.m.	H.P. water pipe to Street Railway cables	5	+2.5	+2.0	+2.2
10/31/14	**Princess street at McDermot avenue.**				
	Manitoba Government Telephone cables to tracks	2	−2.1	−1.3	−1.5
During Morning	Manitoba Government Telephone cables to H.P. water pipe	2	−0.7	−0.5	−0.6
	Manitoba Government Telephone cables to L.P. water pipe	2	−0.3	−0.2	−0.25
..	L.P. water pipe to tracks	..	....	....	*−1.2
6/24/14	**Sargent avenue at McGee street.**				
5.30 p.m.	L.P. water pipe to tracks	60	−3.2	−0.8	−2.0
7/ 2/14	**Selkirk avenue at McGregor street.**				
5.30 p.m.	L.P. water pipe to tracks	60	−5.5	−1.5	−2.3
8/18/14	**Sherbrooke street at Broadway**				
..	L.P. water pipe to tracks	2	−2.4	−1.2	−1.7
6/30/14	**Sherbrooke street at Cornish avenue.**				
5.30 p.m.	L.P. water pipe to tracks	60	−6.5	−1.5	−3.8
8/18/14	**Sherbrooke street at Logan avenue.**				
..	L.P. water pipe to tracks	2	−1.2	0	−0.6
	*Computed Values.				

TABLE NO. 5 (J)

Potential Measurements of Various Underground Pipes and Cable Sheaths Referred to Each Other and Referred to Street Railway Tracks, Winnipeg, Manitoba

Date and Time	Location and Structure Tested	Duration of test Minutes	Potential Volts		
			Max.	Min.	Ave.
11/ 2/14	**Sutherland avenue at Disraeli street.**				
4.15 p.m.	City Light and Power cables to tracks........................	3	−4.0	−2.0	−3.0
10/30/14					
9.30 a.m.	City Light and Power cables to tracks........................	3	−5.0	−4.0	−4.5
9.35 a.m.	City Light and Power cables to L.P. water pipe........	3	−3.5	−2.0	−3.0
..	L.P. water pipe to tracks.....	..	....	....	*−1.5
	*Computed Values.				

TABLE NO. 6

Current Measurements on Low Pressure Water Mains, Winnipeg, Manitoba

Date and Time Start	Location	Size and Kind of Pipe	Duration of Test Min.	Current on Pipe Amperes Max.	Min.	Ave.	Direction
7/17/14 9.45 a.m.	Academy Road between Assiniboine River and Wellington Crescent..	10″ C.I.	32	12.6	0	4.1	North
10.37 a.m.	Broadway east of Osborne street...............	8″ C. I.	33	7.7	1.6	4.3	East
7/18/14 9.50 a.m.	Ellen street north of Notre Dame avenue........	4″ C. I.	30	0.2	0	0.1	North
7/20/14 11.36 a.m.	Harrow street between Assiniboine River and Wellington Crescent..	10″ C. I.	34	15.7	0	7.4	North
10.38 a.m.	Hugo street north of Pembina Highway........	10″ C. I.	32	8.8	0	3.1	South
7/17/14 11.49 a.m.	Hespeler avenue east of Red River...........	12″ C. I.	56	14.7	0	4.5	West
7/ 7/14 5.00 p.m.	Keewatin street north of Logan avenue........	18″ C. I.	1440	21.0	0	5.6	South
7/20/14 3.56 p.m.	Knox street north of Higgins avenue..........	12″ C. I.	31	7.6	2.3	4.8	South
7/17/14 8.49 a.m.	Lipton street north of Portage avenue......	16″ C. I.	31	2.7	0	1.7	South
7/18/14 10.45 a.m.	Lombard street east of Victoria street.......	4″ C. I.	30	7.8	3.2	5.0	East
7/27/14 9.40 a.m.	Main street between Assiniboine River and Mayfair avenue......	10″ C. I.	1440	24.6	0	7.4	North
7/28/14 12.00 noon	Main street south of Atlantic avenue........	8″ C. I.	1110 330	10.5 *8.7	0 0	4.2 *1.2	North South
7/29/14 3.00 p.m.	Montcalm street opposite Desalaberry avenue, Elmwood............	8″ C. I.	1440	17.0	0	4.2	South

*Values during night.

TABLE NO. 6 (A)

Current Measurements on Low-Pressure Water Mains, Winnipeg, Manitoba

Date and Time Start	Location	Size and Kind of Pipe	Duration of Test Min.	Current on Pipe Amperes			Direction
				Max.	Min.	Ave.	
7/ 9/14 4.46 p.m.	McPhillips street south of Logan avenue....	16″ C. I.	55	21.2	2.1	11.2	North
7/ 6/14 6.40 p.m.	McPhillips street at Jarvis avenue..........	18″ C. I.	3	....	....	6.2	South
7/20/14 5.33 p.m.	McPhillips street north of Redwood avenue....	18″ C. I.	21	0	0	0	......
4.45 p.m.	McPhillips street north of Pacific avenue....	16″ C. I.	30	20.5	4.6	11.8	North
7/18/14 11.32 a.m.	Mill street north of Portage avenue near substation............	4″ C. I.	33	9.8	3.1	6.1	South
8/15/14 10.20 a.m.	Notre Dame avenue west of Ellen street.......	6″ C. I.	34	0.6	0	0.3	East
7/22/14 10.00 a.m.	Osborne street south of Woodward avenue (west side of street)..	10″ C. I.	1095	16.0	0	5.6	South
		......	345	*5.6	0	*0.5	North
7/24/14 9.30 a.m.	Osborne street south of Woodward avenue (east side of street)...	6″ C. I.	1095	12.8	0	3.9	South
		......	345	*4.5	0	*0.5	North
10/24/14 11.30 a.m.	Osborne street south of Morley avenue......	6″ C. I.	5	4.3	0.7	2.1	South
8/28/14 11.13 a.m.	Portage avenue west of St. James subway....	10″ C. I.	31	**27.4	**9.8	**18.3	West
7/ 6/14 4.00 p.m.	Portage avenue west of St. James subway....	......	1110	59.0	0	32.0	West
		10″ C. I.	330	*29.0	0	*3.3	East
7/20/14 9.20 a.m.	River avenue between Assiniboine River and Wellington Crescent .	8″ C. I.	25	0	0	0	......
8/28/14 10.25 a.m.	St. James street at intersection with Portage avenue............	6″ C. I.	30	11.5	2.5	7.7	South
9.25 a.m.	St. James street at intersection with Portage avenue............	6″ C. I.	30	**21.0	**6.8	**12.8	South

*Values during night.

**Values with cable drainage connection in St. James substation open.

TABLE NO. 7

Current Measurements on High-Pressure Water Mains, Winnipeg Manitoba

Date and Time Start	Location	Size and Kind of Pipe	Duration of Test Min.	Current on Pipe Amperes Max.	Min.	Ave.	Direction
7/15/14 12.15 p.m.	Arthur street south of McDermot avenue...	10″ C. I.	31	0	0	0	......
7/20/14 3.06 p.m.	Alexander avenue west of Arlington street.....	12″ C. I.	32	19.0	4.7	10.7	West
7/15/14 11.05 a.m.	Alexander avenue east of Stanley street.......	12″ C. I.	31	8.7	0	4.2	East
7/ 8/14 5.00 p.m.	McDermot avenue east of Arlington street...	12″ C. I.	1050	30.0	0	9.9	West
		......	390	*46.0	0	*5.6	East
7/ 9/14 7.10 p.m.	McDermot avenue east of Hargrave street...	12″ C. I.	1230	20.0	0	9.0	East
7/15/14 9.25 a.m.	Portage avenue east of Hargrave street.....	12″ C. I.	55	18.0	3.6	10.0	East
7/ 8/14	Princess street north of Alexander avenue....	12″ C. I.	3	0	0	0	......

*Values during night.

TABLE NO. 8

Current Measurements in Underground Cable Sheaths—Winnipeg, Manitoba

Average Total Currents in all Cable Sheaths at Each Test Location Estimated From Average Readings on Each Cable

Date and Time	Location and Description of Cables	Current Amperes	Direction
7/14/14 Morning	**Assiniboine avenue at Smith street:** 1 City Light and Power cable	0.6	East
7/21/14 10.30 a.m.	**Charlotte street at McDermot avenue:** Manitoba Government Telephone and Fire and Police Telephone cables—		
	9 cables	1.9	South
	18 cables	19.5	North
	2 cables	—*	
10/24/14 10.30 a.m.	**Higgins avenue at Knox street:** 3 City Light and Power cables	0.12	West
10/24/14 9.50 a.m.	**Higgins avenue at McPhillips street:** 3 City Light and Power cables	0.18	West
7/16/14 Afternoon	**King street at Henry avenue:** 5 City Light and Power cables	22.8	South
7/16/14 Afternoon	**King street north of Higgins avenue:** 4 City Light and Power cables	12.2	South
	3 City Light and Power cables	2.1	East
7/21/14 Afternoon	**Lane north of Portage avenue at Hargrave street:** 3 Manitoba Government Telephone cables	8.5	South
	4 Manitoba Government Telephone cables	26.5	East
7/23/14 ..	**Main street at Bannerman avenue:** 3 Manitoba Government Telephone cables	4.2	North
7/23/14 ..	**Main street at Burrows avenue:** 6 Manitoba Government Telephone cables	12.8	South
	6 Manitoba Government Telephone cables	11.9	West
7/23/14 ..	**Main street at Cathedral avenue:** 3 Manitoba Government Telephone cables	3.8	North
7/22/14 Morning	**Main street at Higgins avenue:** 12 Manitoba Government Telephone cables	41.9	South
7/22/14 Morning	**Main street at Market street:** 17 Manitoba Government Telephone cables	78.4	South
7/22/14 3.30 p.m.	**Main street at north end of Main street Bridge:** 3 Manitoba Government Telephone cables	13.2	North

*Small reversing current.

TABLE NO. 8 (A)

Current Measurements in Underground Cable Sheaths—Winnipeg, Manitoba

Average Total Currents in all Cable Sheaths at Each Test Location Estimated From Average Readings on Each Cable

Date and Time	Location and Description of Cables	Current Amperes	Direction
7/22/14 Afternoon	**Main street at Mayfair avenue:**		
	2 Manitoba Government Telephone cables...	9.7	North
7/14/14 Morning	**Main street at McDermot avenue:**		
	West side of manhole:		
	23 City Light and Power cables	75.2	South
	8 City Light and Power cables	15.3	N. to W.
	1 City Light and Power cable.............	1.2	S. to W.
7/20/14 Afternoon	East side of manhole:		
	23 City Light and Power cables	25.4	South
7/23/14	**Main street at Redwood avenue:**		
..	2 Manitoba Government Telephone cables...	5.8	North
	2 Manitoba Government Telephone cables...	19.2	South
7/10/14	**Main street between William avenue and Bannatyne avenue:**		
Morning	10 Manitoba Government Telephone cables..	36.2	South
7/22/14 2.00 p.m.	**Main street at York avenue:**		
	9 Manitoba Government Telephone cables...	17.9	South
7/21/14 9.30 a.m.	**McDermot avenue at Princess street:**		
	Manitoba Government Telephone and Fire and Police Telephone cables:		
	9 cables	50.7	East
	7 cables	—*	
7/24/14	**Notre Dame avenue at Arlington street:**		
..	2 Manitoba Government Telephone cables...	0.1	East
7/16/14 Morning	**Notre Dame avenue at Ellice avenue:**		
	29 City Light and Power cables	39.9	East
	2 City Light and Power cables	2.6	South
7/ 6/14	**Notre Dame avenue at Grand Trunk Pacific Railroad Bridge:**		
10.00 a.m.	1 Fire and Police Telephone cable (other cable negligible current)	0.1	North
7/21/14 2.00 p.m.	**Notre Dame avenue at Hargrave street:**		
	Manitoba Government Telephone and Police Telephone cables:		
	6 cables	5.4	South
	1 cable..................................	2.9	West
	2 cables	4.0	North

*Small reversing current.

TABLE NO. 8 (B)

Current Measurements in Underground Cable Sheaths, Winnipeg, Manitoba

Average Total Currents in All Cable Sheaths at Each Test Location Estimated From Average Readings on Each Cable

Date and Time	Location and Description of Cables	Current Amperes	Direction
7/21/14 Afternoon	**Notre Dame avenue at King street:** 2 Manitoba Government Telephone cables...	15.4	East
7/24/14 ..	**Notre Dame avenue at Sherbrooke street:** 7 Manitoba Government Telephone cables...	2.8	East
7/6/14 9.00 a.m.	**Notre Dame avenue at Victoria street:** 2 Fire and Police Telephone cables.........	1.4	East
	2 Manitoba Government Telephone cables...	2.4	West
	(The Fire and Police Telephone cable feeding into the Mill street substation was cut off when this test was made).		
7/23/14 Morning	**Osborne street at Arnold avenue:** 1 Manitoba Government Telephone cable....	1.3	South
7/ 4/14 11.30 a.m.	1 Manitoba Government Telephone cable....	0.9	South
7/23/14 Morning	**Osborne street at Corydon avenue:** 8 Manitoba Government Telephone cables...	3.0	South
7/23/14 Morning	**Osborne street at Kylemore avenue:** 2 Manitoba Government Telephone cables...	0	.....
7/23/14 Morning	**Osborne street at River avenue:** 2 Manitoba Government Telephone cables...	2.4	North
	6 Manitoba Government Telephone cables...	7.9	East
7/22/14 4.00 p.m.	**Princess street at Market street:** 4 Manitoba Government Telephone cables...	3.3	East
7/ 4/14 ..	**Portage avenue at Clifton street:** 3 Manitoba Government Telephone cables...	3.9	West
7/24/14 ..	**Portage avenue at Colony street:** 9 Manitoba Government Telephone cables...	25.1	East
7/24/14 ..	**Portage avenue at Home street:** 7 Manitoba Government Telephone cables...	4.2	West

TABLE NO. 8 (C)

Current Measurements in Underground Cable Sheaths—Winnipeg, Manitoba

Average Total Currents in all Cable Sheaths at Each Test Location Estimated From Average Readings on Each Cable

Date and Time	Location and Description of Cables	Current Amperes	Direction
10/14/14	**Portage avenue at Hargrave street:**		
	Southwest corner:		
	7 Street Railway cables	13.7	East
	Northwest corner:		
	5 Street Railway cables	21.6	East
7/21/14 Afternoon	Southeast corner:		
	5 Manitoba Government Telephone cables...	25.1	East
7/ 9/14 2.00 p.m.	**Portage avenue at Main street:**		
	East side of Main street:		
	Manitoba Government Telephone and Fire and Police Telephone cables:		
	14 cables	99.5	East
		*20.0	East
	1 cable	3.5	South
	1 cable	0.1	Reversing
	(12 more cables were in such position that they could not be tested)		
10/14/14	Northwest corner:		
..	18 Street Railway cables	64.4	East
10/14/14	Southwest corner:		
..	21 Street Railway cables	52.4	East
7/ 9/14 4.00 p.m.	**Portage avenue east of Rorie street:**		
	7 Manitoba Government Telephone cables...	31.4	East
		*5.1	East
7/15/14 9.00 a.m.	10 Manitoba Government Telephone cables from rear of Main Telephone Exchange...	88.5	North
		*17.6	North
	1 Manitoba Government Telephone cable from rear of Main Telephone Exchange to Bank of Montreal building...........	15.0	Into Bank

*Values with cable drainage connections open.

TABLE NO. 8 (D)

Current Measurements in Underground Cable Sheaths—Winnipeg, Manitoba

Average Total Currents in All Cable Sheaths at Each Test Location Estimated From Average Readings on Each Cable

Date and Time	Location and Description of Cables	Current Amperes	Direction
10/14/14	**Portage avenue at Smith street:**		
	Southwest corner:		
	7 Street Railway cables..................	13.7	East
	Northeast corner:		
	Street Railway manhole:		
	5 Street Railway cables..................	19.9	East
7/15/14 Morning	City Light and Power manhole:		
	South side of manhole:		
	7 City Light and Power cables...........	7.2	East
	7 City Light and Power cables...........	1.2	South
	16 City Light and Power cables...........	9.1	North
7/15/14 Morning	North side of manhole:		
	25 City Light and Power cables...........	30.7	East
	7 City Light and Power cables...........	2.2	South
7/24/14	**Portage avenue at Spence street:**		
..	11 Manitoba Government Telephone cables..	19.4	East
7/24/14	**Portage avenue at Strathcona street:**		
..	2 Manitoba Government Telephone cables...	5.4	West
		*1.9	West
10/14/14	2 Street Railway cables..................	20.9	West
..		*1.0	West
7/23/14	**Salter street at Burrows avenue:**		
..	8 Manitoba Government Telephone cables...	5.9	West
7/23/14	**Salter street at Logan avenue:**		
..	4 Manitoba Government Telephone cables...	3.3	West
	1 Manitoba Government Telephone cable....	5.4	East
7/23/14	**Salter street at Machray avenue:**		
..	3 Manitoba Government Telephone cables...	1.2	East
7/23/14	**Salter street at Magnus avenue:**		
..	8 Manitoba Government Telephone cables...	8.1	South
7/23/14 Morning	**Wellington Crescent near Hugo street:**		
	1 Manitoba Government Telephone cable....	2.6	North
	*Values with cable drainage connections open.		

TABLE NO. 9

Current Measurements in Drainage Connections From Underground Cable Sheaths to Railway Return Conductors—Winnipeg, Manitoba Average Values Between 6.00 a.m. and Midnight

Date	Location, Number, Size and Connections of Drainage Cable	Average Current Amperes
8/ 7/14	**Substation No. 3—Portage avenue at St. James street:** One-211-600 circular mil cable from the lead sheaths of the Winnipeg Electric Railway cables to negative busbar in substation	44.0
7/10/14	**Substation No. 1—Mill street at River:** Two-336-000 circular mil cables from the lead sheaths of the Manitoba Government Telephone cables to railway return feeders in Portage avenue east of Main street opposite the main telephone exchange	230.0
8/ 3/14	One-336-000 circular mil cable from the lead sheaths of the Winnipeg Electric Railway Co. cables at corner of Portage avenue and Main street to the negative busbar in substation No. 1	72.0
8/ 5/14	One-211-600 circular mil cable from the lead sheaths of the Winnipeg Electric Railway Co. cables at substation No. 1 to the negative busbar in this station	93.0
8/11/14	One-211-600 circular mil cable from the 2-inch Pintsch gas pipe to railway return feeders near substation No. 1	66.0
	Total for substation No. 1 district	461.0

TABLE NO. 10

Locations and Constants of Permanent Electrical Test Stations on Low-Pressure Water Mains—Winnipeg, Manitoba

Location	Size and Kind of Pipe	Weight per foot without bell Pounds	Distance Between Contacts Feet	Amperes Per Millivolt K
Academy Road between Assiniboine River and Wellington Crescent	10″ C. I.	64.5	5.0	9.0
Broadway east of Osborne street	8″ C. I.	47.6	3.9	8.4
Ellen street north of Notre Dame avenue	4″ C. I.	16.7	7.5	1.6
Harrow street between Assiniboine River and Wellington Crescent	10″ C. I.	70.8	10.0	4.9
Hugo street north of Pembina Highway	10″ C. I.	70.8	10.0	4.9
Hespeler avenue east of Red River	12″ C. I.	83.5	9.6	6.1
Keewatin street north of Logan avenue	18″ C. I.	153.2	4.6	23.2
Knox street north of Higgins avenue	12″ C. I.	83.5	7.6	7.6
Lipton street north of Portage avenue	16″ C. I.	129.3	10.0	9.0
Lombard street east of Victoria street	4″ C. I.	20.2	6.2	2.3
Main street between Assiniboine River and Mayfair avenue	10″ C. I.	64.5	5.5	8.2
Main street south of Atlantic avenue	8″ C. I.	47.6	9.3	3.6
Montcalm street opposite Desalaberry avenue, Elmwood	8″ C. I.	47.6	9.7	3.4
McPhillips street south of Logan avenue	16″ C. I.	129.3	8.5	10.6
McPhillips street north of Redwood avenue	18″ C. I.	153.2	7.0	15.2
McPhillips street north of Pacific avenue	16″ C. I.	129.3	9.8	9.1
Mill street north of Portage avenue near substation	4″ C. I.	20.2	5.3	2.6
Notre Dame avenue west of Ellen street	6″ C. I.	32.8	8.0	2.9
Osborne street south of Woodward avenue (west side of street)	10″ C. I.	70.8	4.3	11.3
Osborne street south of Woodward avenue (east side of street)	6″ C. I.	32.8	7.2	3.2
Portage avenue west of St. James subway	10″ C. I.	70.8	10.0	4.9
River avenue between Assiniboine River and Wellington Crescent	8″ C. I.	52.1	4.6	7.8
St. James street at intersection with Portage avenue	6″ C. I.	35.8	10.1	2.5

TABLE NO. 11

Locations and Constants of Permanent Electrical Test Stations on High-Pressure Water Mains—Winnipeg, Manitoba

Location	Size and Kind of Pipe	Weight Per Foot Without Bell Pounds	Distance Between Contacts Feet	Amperes Per Millivolt K
Arthur street south of McDermot avenue....	10″ C. I.	96	10.0	6.7
Alexander avenue west of Arlington street....	12″ C. I.	132	7.7	11.9
Alexander avenue east of Stanley street......	12″ C. I.	132	7.9	11.6
McDermot avenue east of Arlington street...	12″ C. I.	132	8.0	11.5
McDermot avenue east of Hargrave street...	12″ C. I.	132	4.6	20.0
Portage avenue east of Hargrave street......	12″ C. I.	132	5.1	18.0
Princess street north of Alexander avenue....	12″ C. I.	132	5.2	17.7

PLATE 1

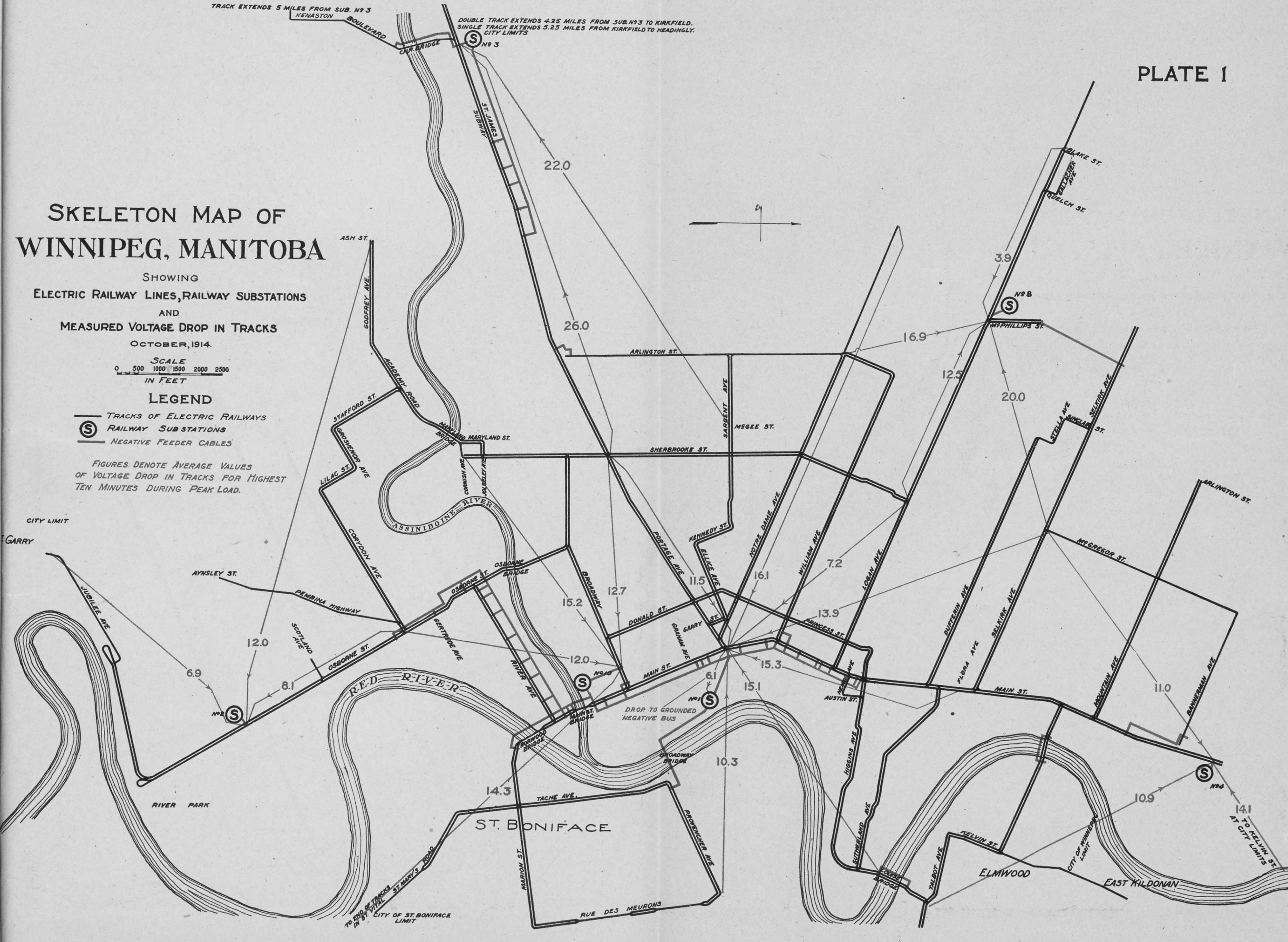
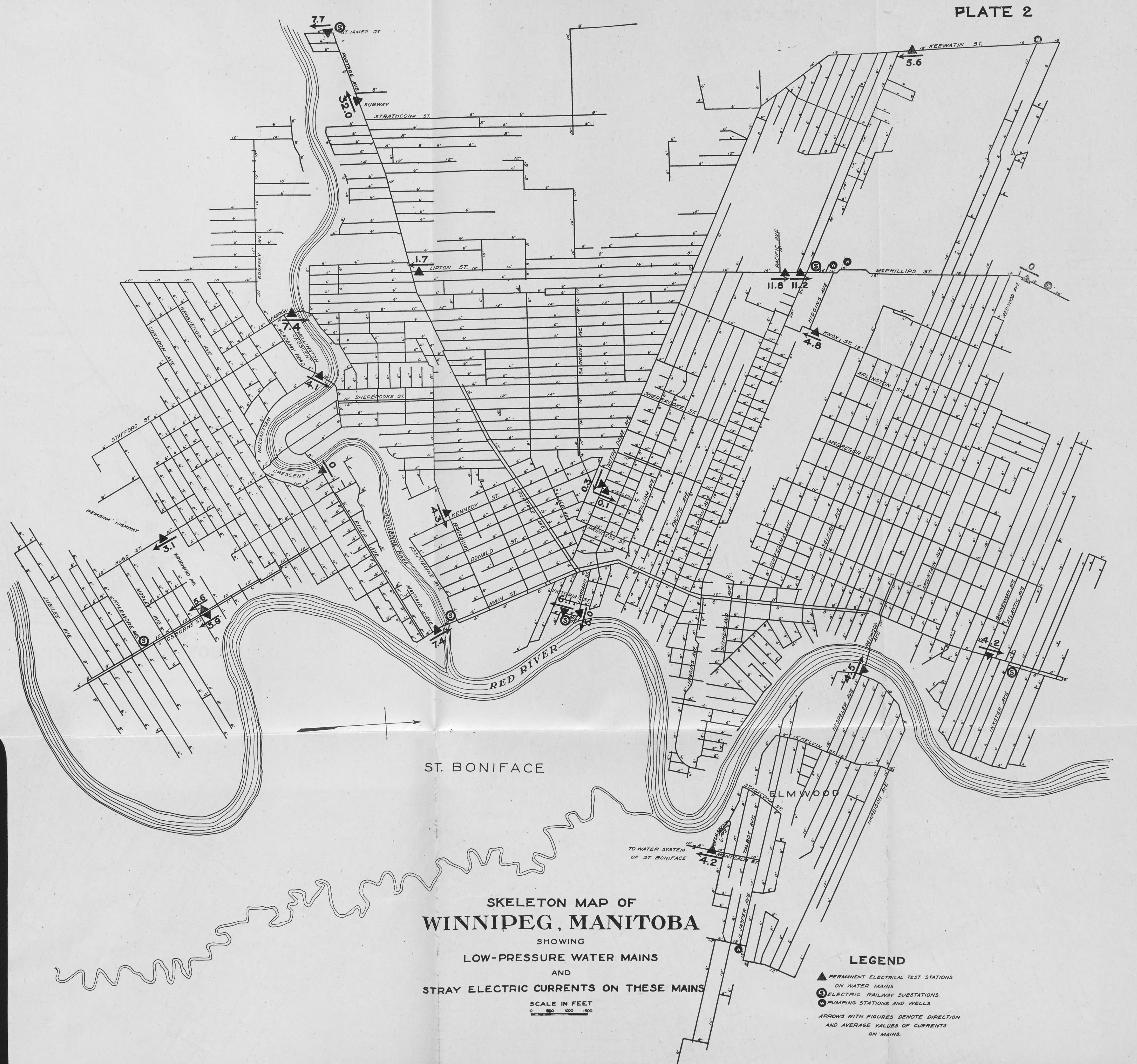

SKELETON MAP OF
WINNIPEG, MANITOBA
SHOWING
ELECTRIC RAILWAY LINES, RAILWAY SUBSTATIONS
AND
MEASURED VOLTAGE DROP IN TRACKS
OCTOBER, 1914.
SCALE
0 500 1000 1500 2000 2500
IN FEET
LEGEND
TRACKS OF ELECTRIC RAILWAYS
RAILWAY SUB STATIONS
NEGATIVE FEEDER CABLES
FIGURES DENOTE AVERAGE VALUES OF VOLTAGE DROP IN TRACKS FOR HIGHEST TEN MINUTES DURING PEAK LOAD.
TRACK EXTENDS 5 MILES FROM SUB. Nº 3
KENASTON BOULEVARD
C.N.R. BRIDGE
DOUBLE TRACK EXTENDS 4.25 MILES FROM SUB. Nº 3 TO KIRKFIELD.
SINGLE TRACK EXTENDS 5.25 MILES FROM KIRKFIELD TO HEADINGLY.
CITY LIMITS
Nº 3
ST. JAMES SUBWAY
22.0
26.0
ARLINGTON ST.
SARGENT AVE
MCGEE ST.
SHERBROOKE ST.
BLAKE ST.
QUELCH ST.
3.9
Nº 8
MCPHILLIPS ST.
16.9
12.5
20.0
STELLA AVE
SINCLAIR ST.
SELKIRK AVE
ASH ST.
GODFREY AVE.
ACADEMY ROAD
STAFFORD ST.
GROSVENOR AVE
LILAC ST.
MARYLAND BRIDGE
MARYLAND ST.
CORNISH AVE
ASSINIBOINE RIVER
CORYDON AVE
CITY LIMIT
GARRY
JUBILEE AVE
AYNSLEY ST.
PEMBINA HIGHWAY
OSBORNE ST.
OSBORNE BRIDGE
GERTRUDE AVE
SCOTLAND AVE
RIVER AVE
BROADWAY
12.7
15.2
KENNEDY ST.
ELLICE AVE
PORTAGE AVE
NOTRE DAME AVE
WILLIAM AVE
LOGAN AVE
11.5
16.1
7.2
13.9
DONALD ST.
GRAHAM AVE
GARRY ST.
PRINCESS ST.
12.0
6.9
8.1
Nº 2
RED RIVER
MAIN ST.
Nº 10
6.1
Nº 1
15.3
15.1
DROP TO GROUNDED NEGATIVE BUS
AUSTIN ST.
MAIN ST. BRIDGE
NORWOOD BRIDGE
BROADWAY BRIDGE
10.3
14.3
TACHE AVE.
ST. BONIFACE
MARION ST.
PROVENCHER AVE
RUE DES MEURONS
ST. MARY'S ROAD
TO END OF TRACKS IN ST. VITAL
CITY OF ST. BONIFACE LIMIT
RIVER PARK
HIGGINS AVE
SUTHERLAND AVE
LOUISE BRIDGE
DUFFERIN AVE
FLORA AVE
SELKIRK AVE
MOUNTAIN AVE
BANNERMAN AVE
ARLINGTON ST.
MCGREGOR ST.
MAIN ST.
11.0
Nº 4
14.1
TO KELVIN ST. AT CITY LIMITS
10.9
KELVIN ST.
CITY OF WINNIPEG LIMIT
TALBOT AVE
ELMWOOD
EAST KILDONAN

PLATE 2



SKELETON MAP OF

WINNIPEG, MANITOBA

SHOWING

LOW-PRESSURE WATER MAINS

AND

STRAY ELECTRIC CURRENTS ON THESE MAINS

SCALE IN FEET

0 500 1000 1500

LEGEND

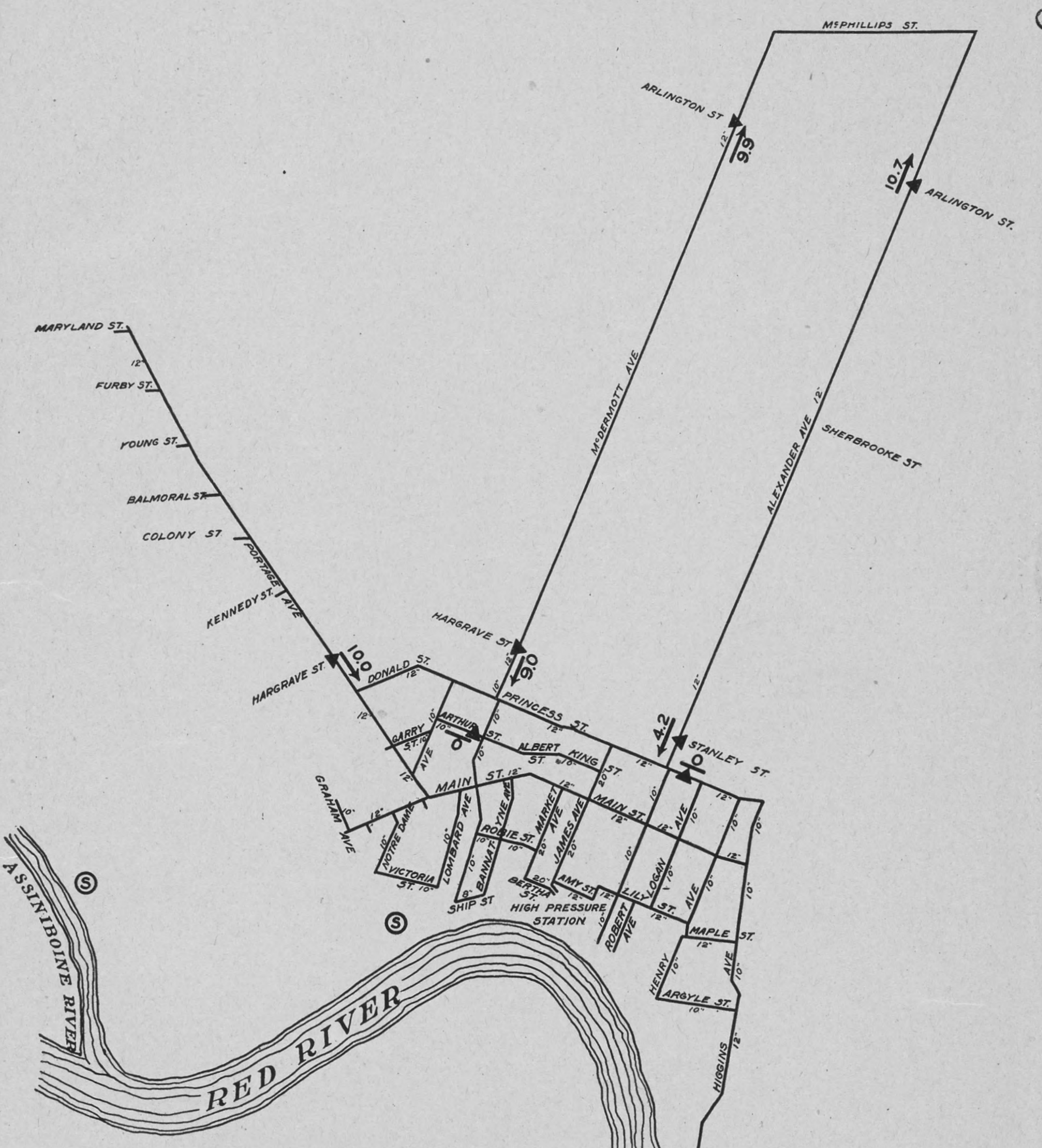
▲ PERMANENT ELECTRICAL TEST STATIONS ON WATER MAINS

Ⓢ ELECTRIC RAILWAY SUBSTATIONS

Ⓦ PUMPING STATIONS AND WELLS

ARROWS WITH FIGURES DENOTE DIRECTION AND AVERAGE VALUES OF CURRENTS ON MAINS.

PLATE 3



SKELETON MAP OF
WINNIPEG, MANITOBA
SHOWING
HIGH-PRESSURE WATER MAINS
AND
STRAY ELECTRIC CURRENTS ON THESE MAINS
JULY, 1914

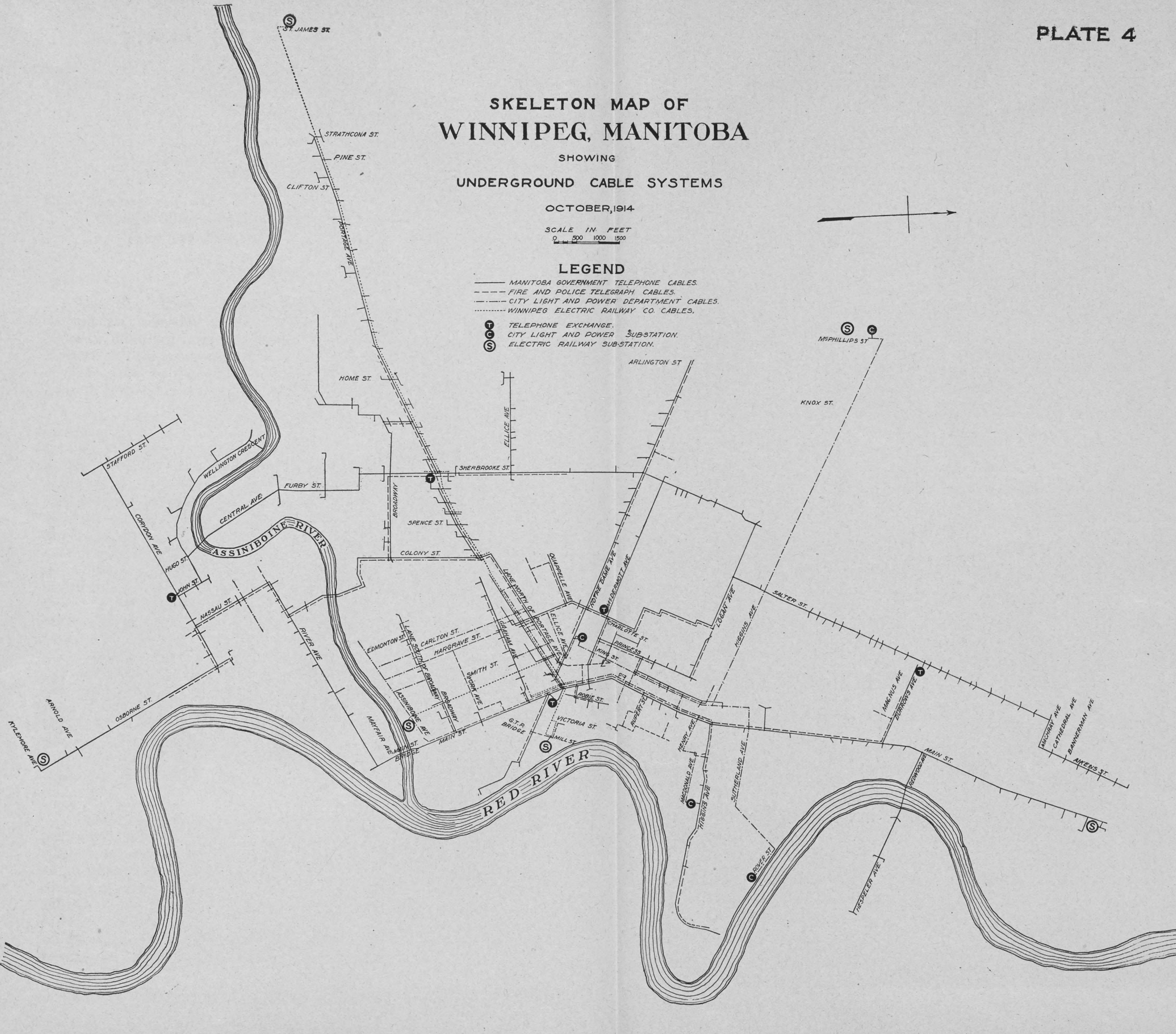
SCALE IN FEET
0 500 1000 1500

LEGEND

▲ PERMANENT ELECTRICAL TEST STATION
Ⓢ ELECTRIC RAILWAY SUBSTATION

ARROWS WITH FIGURES DENOTE DIRECTION AND AVERAGE CURRENTS ON MAIN.

PLATE 4


SKELETON MAP OF
WINNIPEG, MANITOBA
SHOWING
UNDERGROUND CABLE SYSTEMS
OCTOBER, 1914
SCALE IN FEET
0 500 1000 1500
LEGEND
MANITOBA GOVERNMENT TELEPHONE CABLES.
FIRE AND POLICE TELEGRAPH CABLES.
CITY LIGHT AND POWER DEPARTMENT CABLES.
WINNIPEG ELECTRIC RAILWAY CO. CABLES.
TELEPHONE EXCHANGE.
CITY LIGHT AND POWER SUB-STATION.
ELECTRIC RAILWAY SUB-STATION.
ST. JAMES ST.
STRATHCONA ST.
PINE ST.
CLIFTON ST.
PORTAGE AVE.
HOME ST.
ELLICE AVE.
ARLINGTON ST.
McPHILLIPS ST.
KNOX ST.
STAFFORD ST.
WELLINGTON CRESCENT
FURBY ST.
SHERBROOKE ST.
CENTRAL AVE.
CORYDON AVE.
BROADWAY
SPENCE ST.
ASSINIBOINE RIVER
HUGO ST.
COLONY ST.
JOHN ST.
NASSAU ST.
RIVER AVE.
QU'APPELLE AVE.
LANE NORTH OF PORTAGE AVE.
NOTRE DAME AVE.
McDERMOTT AVE.
LOGAN AVE.
HIGGINS AVE.
SALTER ST.
CHARLOTTE ST.
PRINCESS
KING ST.
EDMONTON ST.
CARLTON ST.
LANE SOUTH OF BROADWAY
MARGRAVE ST.
GRAHAM AVE.
SMITH ST.
YORK AVE.
ROBIE ST.
ASSINIBOINE AVE.
VICTORIA ST.
RUPERT ST.
HENRY AVE.
MAGNUS AVE.
BURROWS AVE.
MACHRAY AVE.
CATHEDRAL AVE.
BANNERMAN AVE.
ARNOLD AVE.
OSBORNE ST.
KYLEMORE AVE.
MAYFAIR AVE.
MAIN ST. BRIDGE
MAIN ST.
G.T.P. BRIDGE
MILL ST.
RED RIVER
MACDONALD AVE.
HIGGINS AVE.
SUTHERLAND AVE.
REDWOOD AVE.
AIKENS ST.
DOVER ST.
HESPELER AVE.

APPENDIX.

PRELIMINARY REPORT.

H. A. Robson, Esq., K.C.,
Public Utilities Commissioner,
Winnipeg, Manitoba.

Re Electrolysis Investigation.

Dear Sir,—I beg to give you in the following a preliminary report on temporary remedial measures which were installed on underground cables in Winnipeg under my personal supervision during October and November, 1914, where these *cables were found to be in serious danger of destruction by electrolysis.* This work of installation was undertaken in accordance with my verbal understanding with you.

Stray electric currents are produced by the electric railways operating in Winnipeg due to voltage drop in the tracks of these railways. This voltage drop is caused by the current returning by way of the tracks to the railway substations. These stray currents are endangering underground metallic structures, such as pipes and cables, from electrolysis. This danger is greatest in the immediate neighborhood of each of the six electric railway substations supplying direct current for the operation of these railways, because the tracks nearest each substation are directly connected to the negative busbar of the substation, with the result that these stray currents flow on the underground sructures towards these substations. These stray currents therefore leave the underground structures in the vicinity of each railway substation to return to the tracks and to any other grounded conductors which are connected to the negative busbar in the substation, thus resulting in danger to these structures. The only safe and permanent plan for minimizing the danger from electrolysis, as well as from possible fires or other dangers which may be produced by these stray currents, is to remove as much of the return currents from the tracks by adequate insulated return feeders as will reduce the voltage drop and correspondingly reduce the stray currents through ground to sufficiently low values to reasonably safeguard all underground structures. I will include a recommendation to this effect in my formal report to you.

Inasmuch, however, as considerable time may elapse before such permanent railway changes can be made, I have protected the cables where these were in acute danger from electrolysis by electrical drainage as an immediate temporary relief measure. This electrical drainage consists in removing the stray currents from the cable sheaths at each substation by a suitable copper wire connecting the lead sheaths to the railway return circuit, thus removing this current by metallic conduction and preventing destruction at this point of leaving by electrolysis. Electrical drainage is the only relief measure which could

be immediately applied at small expense to protect the cable systems. *No temporary measures have been applied to protect underground piping systems because electrical drainage cannot safely be applied to pipes,* these not being continuous and uniform electrical conductors as are lead sheaths of cables, and *no other relief measures are available which could be temporarily applied to these pipes.* The thin lead walls of underground cable sheaths are also many times more liable to be destroyed by electrolysis by a given amount of stray current than are underground iron pipes.

There are four principal underground cable systems in Winnipeg as follows: Manitoba Government Telephone cables, City Electric Light and Power cables, Winnipeg Electric Railway Light and Power cables, and City Fire and Police Telegraph cables. The first three of these cable systems are carried in independent conduits. The fire and police telegraph cables are carried in the telephone conduits wherever there are underground telephone cables, while in other localities these are also carried in independent conduits. There are also a relative small number of underground telegraph cables belonging to several of the steam railroads. These telegraph cables are carried in the telephone conduits. The lead sheaths of all cables in any one manhole are bonded to each other by suitable copper bond wires. These telegraph cables and the fire and police telegraph cables where they are in telephone conduits, may therefore be considered as part of the telephone cable system. Most of the underground cables in Winnipeg excepting the telephone cables have been installed during the past few years.

Electrical drainage had sometime ago been applied near the Mill Street railway substation to the underground telephone cables and to the underground street railway cables in order to protect these cables against destruction by electrolysis in this region. Electrical drainage had likewise been applied to the street railway cables near the St. James railway substation for the same purpose. The Manitoba Government Telephone Commission had also found that its underground cables were in serious danger from electrolysis in the following railway substation districts: Portage avenue at St. James street, Osborne street at Kylemore avenue, and Main street at Inkster avenue. This Commission had for this reason requested that temporary electrical drainage connections be installed in these substation districts, and has filed with the Public Utilities Commission correspondence with the Winnipeg Electric Railway Company referring to such temporary electrical drainage connections, but such connections were not installed, as no agreement regarding them was reached.

The City Electrical Department also reports that it has had trouble from electrolysis on the underground fire and police telegraph cables in Mill street.

Summary and conclusions.—Electrical drainage connections have been applied from the underground cable systems to the railway return circuit under my personal supervision in five electric railway substation districts as follows:

Cables Protected.	Location of Substation.	Date Substation was placed in service.
Telephone	Osborne Street at Kylemore Avenue	Sept. 5, 1909
Telephone	Portage Avenue at St. James Street	Oct. 14, 1909
Telephone	Main Street near Inkster Avenue	Dec. 29, 1909
Telephone and City Light & Power	Assiniboine Avenue at Garry Street	Sept. 25, 1912
City Light & Power	Logan Avenue at McPhillips Street	Nov. 18, 1912

It will also be noted that these substations have been in service a relatively short time.

The work of installing this electrical drainage has been done jointly by the Manitoba Government Telephone Commission, by the City Electric Light and Power Department, and by the Winnipeg Electric Railway Company.

Tests made after these electrical drainage connections were applied, show that the underground cables in these districts are now *relatively safe from destruction by electrolysis. The electrical drainage of the underground cable systems renders these cables negative in potential to underground water pipes and therefore sets up a tendency for currents to flow from water pipes to these cable sheaths, thus tending to injure the water pipes by electrolysis.* The currents drained from the cables over these drainage connections are however relatively small, due to the fact that the number of cables that were protected by electrical drainage in any one district was relatively small, so that *these drainage connections probably have not seriously increased the danger of the water piping system from electrolysis.*

The electrical drainage cables installed in the above five railway substations have been brought into the substations, and a knife switch has been inserted in circuit with each of these cables in the substation. These switches are located in convenient places so that the drainage circuit can be easily opened by the station operator when the particular substation is shut down, so as to prevent current from flowing to the cable sheaths and endangering them from electrolysis. In order that the amount of current drained from the underground cables in these regions may be conveniently noted at any time, it will be advisable to have an ammeter, or a millivoltmeter suitably calibrated with a length of the drainage cable used as a shunt, installed in each of these drainage connections.

In the Mill street railway substation district, the street railway cables had for some time past been drained to the railway return conductors at Portage avenue and Main street, and also directly at the Mill street substation; the telephone cables had likewise been drained to the railway return conductors in Portage avenue east directly in front of the Main telephone exchange. Tests made during June and July last showed that the negative busbar in the Mill street substation was grounded through accidental contacts between iron conduits or pipes and return feeder cables. This rendered the ground at the Mill street substation from 4 to about 7 volts lower in potential than the ground at Portage avenue and Main street, at which latter place the tracks are at

the lowest potential for this substation district. As this increase in voltage drop through ground, due to this grounding of the negative busbar, increased the total stray currents, and had already caused destructive pitting from electrolysis of an iron conduit and the lead sheathing of a fire and police telegraph cable in this conduit, I requested to have this busbar cleared of all grounds. This was done during the past summer and this has substantially removed the acute danger from electrolysis formerly existing in Mill street. As it is important to maintain this busbar insulated, it will be desirable to install a voltmeter in the Mill street substation permanently connected to indicate the potential difference between the negative busbar and a water pipe, which latter may be taken as at ground potential. The indication of this voltmeter should be recorded at least once every day during peak load. This voltmeter should show the water pipe from 4 to 7 volts positive to the negative busbar, depending upon load conditions. A low voltage reading would indicate grounding of the busbar. If this should develop at any time, steps should be taken to remove the ground connection.

It was found that the drainage connections from the telephone and the street railway cables also drained current from the city light and power cables and from the city water pipes, so that metallic contacts between these systems must exist. The potential differences between the various underground systems on Portage avenue were, however, not sufficiently low to be safe. It was found that some improvement could be made by disconnecting the drainage connection from the street railway cables to the negative busbar at the Mill street substation, and I have requested that this drainage connection be maintained disconnected. A drainage connection also existed between a two-inch Pintsch gas pipe and the railway return conductors near the Mill street substation, and this drainage connection should also be disconnected. These two drainage connections at the Mill street substation can now be safely left disconnected because the negative busbar in this substation is now insulated from ground.

Attempts to improve the potential relations between the various cable systems in Portage avenue and in Main street were made by connecting a tie drainage cable from the city light and power cables to the telephone cables, and from there to the street railway cables, at the corner of Portage avenue east and Main street. These tests showed however that a current averaging several hundred amperes during day load would have to be drained from the city light and power cables to bring them to safe potential conditions in this immediate vicinity. The total current drained from the cables in this district would be increased by such a tie connection but not by the amount of current flowing over the tie connection, because the latter current would come not only from the city light and power cables, but also from other cables and from pipes, through metallic contacts between them. *The drainage of such large currents from the city light and power cables would, therefore, involve the danger of large interchange of current between various cables*

and pipes at new and unknown points of contact, and these would undoubtedly exist largely between service in buildings, where such currents would constitute a fire hazard. In view of this, and as the present drainage connections are *only temporary relief measures,* I have not made such connections and would suggest that no further drainage connections be made in the Mill street district at present.

It should be pointed out that the temporary electrical drainage connections which have been installed afford protection against electrolysis from stray currents which are leaving these cable sheaths to flow to the street railway tracks in the neighborhood of the substations, in which locations the danger from electrolysis to these cable systems was most acute. *There are undoubtedly locations where considerable potential differences exist between adjacent underground cables or between such cables and pipes, and where there is corresponding danger from electrolysis due to currents flowing between such structures. Inasmuch as these drainage installations are temporary, I have not considered it necessary to make extensive tests to determine where such points of possible danger exist.*

Owing to the great importance of protecting the underground cable systems against destruction by electrolysis, it would be desirable to make periodic electrical tests of these cable systems.

Recommendations: *I beg to offer the following recommendations* for the purpose of assuring the greatest possible protection to the underground cable systems of Winnipeg, *until more effective and more permanent improvements have been made*:

(1) That the Winnipeg Electric Railway Company be requested to maintain disconnected the drainage connection from their cable sheaths to the railway return conductors directly at the Mill street substation, and also to maintain disconnected the drainage connection from the Pintsch gas pipe to the railway return conductors at the Mill street substation.

(2) That the Winnipeg Electric Railway Company be requested to maintain the switches in the drainage connections in every railway substation open whenever this substation is shut down, so as to prevent current from being delivered to the cable systems over the drainage connections which would endanger these cables from electrolysis.

(3) That the Winnipeg Electric Railway Company be requested to install ammeters or other suitable meters for measuring current flow in each of the drainage connections from underground cables entering the following five railway substations:

Osborne street at Kylemore avenue;
Portage avenue at St. James street;
Main street at Inkster avenue;
Assiniboine avenue at Garry street;
Logan avenue at McPhillips street.

(4) That the Winnipeg Electric Railway Company be requested to record the readings of the ammeters in these drainage connections at least once every day during the peak load hour, and that these records be open to the inspection of the authorized representative of the Public Utilities Commission and to the city electrician; and to the authorized representative of the Manitoba Government Telephone Commission and of the City Electric Light and Power Department, where the Commission or the Electric Light Department have drainage connections from their cables in the substation district.

(5) That the Winnipeg Electric Railway Company be requested to install a suitable voltmeter between the negative busbar and the water service pipe in the Mill street substation for the purpose of indicating whether the negative busbar is being maintained insulated from ground directly at the substation, and that readings of this voltmeter be taken and recorded by a railway company representative at least once every day during peak load hour, and that the record of this voltage be open to the inspection of the authorized representative of the Public Utilities Commission and to the inspection of the city electrician. If the indication of this voltmeter should fall at any time to such a low value as to indicate grounding of the negative busbar, steps should be taken by the railway company to remove such ground connection.

(6) That periodic tests at least once every year be made to determine the electrical condition of the various cable systems. These tests are preferably to be made jointly by representatives of the various interests owning the cable systems under the supervision of the authorized representative of the Public Utilities Commission. These electrical tests are to include simultaneous potential measurements between the lead sheaths of the various cables and between these sheaths and adjoining water pipes and street railway tracks; these tests are to be made at intervals of about three blocks throughout the city where underground cables are located. In the neighborhood of each railway substation, current measurements on all of the cables in two or three manholes nearest the railway substation should also be made, and the total current on these cable sheaths be compared with the total current drained from them to the street railway substation. Current measurements in the tie drainage connection from the telephone cables to the railway return circuit in Portage avenue east and in the tie drainage connection between the telephone cables and the street railway cables in Portage avenue at Strathcona street should also be included in these tests.

In the following pages are given the detailed results of the investigation made in each substation district.

Respectfully submitted,

ALBERT F. GANZ.

DETAILED RESULTS OF INVESTIGATION.

District of Osborne street and Kylemore avenue railway substation. —This substation was placed in service September 5, 1909. The negative busbar in this railway substation is connected to the double tracks on Osborne street by underground negative feeder cables. There are no other return feeders from the tracks to the substation. Government telephone cables are carried in underground conduits on Osborne street from the center of the city south to Kylemore avenue, and from here these cables continue south overhead. At Kylemore avenue the lead sheaths of these telephone cables were found to be from 3 to 6 volts positive in potential to the tracks, and about one volt average positive to the water pipes. At Arnold avenue, a few blocks north from Kylemore avenue, the cables were from one to nearly five volts positive to the tracks. On July 4, 1914, the manhole at this corner was found partially flooded with water, submerging the cables. The cable sheaths were also found to be about one volt average positive to the water in the manhole. The cable sheaths here showed marked pittings evidently caused by electrolysis. Stray current was also found on these telephone cable sheaths on Osborne street flowing south toward the Kylemore avenue railway substation; this current had a total average value on all cables of 3.0 amperes at Corydon avenue and of 1.3 amperes at Arnold avenue, while at Kylemore avenue there was no measurable current, indicating loss of current from the cable sheaths north of Kylemore avenue. It is, therefore, evident that these telephone cable sheaths were in very serious danger from electrolysis on Osborne street for some distance north from Kylemore avenue. I am, in fact, of the opinion that these cables must already have become severely damaged from electrolysis so that a break from their present weakened condition may be expected in this region.

In order to protect these cables against this serious danger from electrolysis, it was decided to electrically drain these cables to the railway return circuit as a temporary relief measure. After some experimenting, a 105 500-cir. mil copper drainage cable was installed from the cable sheaths in the manhole at Kylemore avenue to the negative busbar in the Kylemore avenue substation. The Telephone Commission provided a duct for carrying this cable from the manhole to a pole, and connected the cable to the lead sheaths in this manhole. The railway company supplied the cable and completed the installation to the negative busbar in the railway substation, with a knife switch in circuit placed in the substation.

A current measurement in this drainage cable showed an average of 12 amperes drained from the cable sheaths to the negative busbar during average day load conditions. The potential of the telephone cable sheaths referred to the street railway tracks at Kylemore avenue was reduced by this drainage connection from its former highly positive condition to a slightly positive condition averaging about 0.2 volt. A number of potential measurements were also made along Osborne street from Kylemore to Corydon avenue, the limit to which this substation feeds to the north.

From Kylemore avenue north to Scotland avenue, the telephone cable sheaths remained slightly positive to the tracks, and north from Scotland avenue these cable sheaths became negative in potential to the tracks, this negative potential reaching an average of about 1.8 volts at Corydon avenue. The telephone cables, after being drained, also became 0.8 volt average negative to the water pipes at Kylemore avenue, and remained negative to these water pipes with decreasing values to Corydon avenue, where these cables and water pipes were practically at the same potential.

These tests show that the drainage of these telephone cables at Kylemore avenue has substantially removed the danger from electrolysis to which these cables were formerly subjected in this region. As there are but few telephone cables in this part of Osborne street, and since the total current drained is relatively small, I would not expect that the draining of these cables has largely increased the danger to the water pipes in this region from electrolysis. This is confirmed by the fact that current measurements made on the water mains on the east and west sides of Osborne street at Woodward avenue, did not show any change in these currents when the telephone drainage connection was opened and closed.

The City Light and Power Department does not have underground cables in the region of the Kylemore avenue railway substation.

District of Portage avenue and St. James street railway substation. —This substation was placed in service October 14, 1909. The negative busbar in this substation is connected to the double tracks on Portage avenue by large underground negative feeder cables. One 500 000-cir. mil return feeder also parallels the tracks for some distance east on Portage avenue, and one 350 000-cir. mil return feeder parallels the tracks south from Portage avenue over the bridge crossing the Assiniboine River. Government telephone cables are carried in underground conduits on Portage avenue west of Strathcona street. From this point these cables are carried overhead on the south side of Portage avenue to a point just west of the St. James subway, then are carried through an underground conduit across the street to a pole on the north side of Portage avenue, and from here continue west overhead on Portage avenue for about six miles. The lead sheaths of the underground cables are electrically connected to the lead sheaths of these overhead cables through the messenger wires. The underground cables are carried in ducts, parallel and close to the ducts containing street railway power cables, and also parallel to the street railway tracks on Portage avenue.

The railway substation supplying direct current for the street railway system in this region and east to Sherbrooke street is located on Portage avenue at St. James street, about one-half mile west from Strathcona street. The lead sheaths of the street railway cables have for some time past been electrically drained to the negative busbar in the substation by means of a 211 600-cir. mil copper drainage cable,

connected to the cable sheaths at a point one block east of the substation, and carried in the underground conduit to the substation. The all-day average current drained by this drainage connection was 44 amperes.

Electrical measurements on the underground telephone cable sheaths at Strathcona street showed these sheaths to be from 2 to 6 volts positive in potential to the street railway tracks, and from 5 to 12 volts positive to the sheaths of the street railway cables. Current measurements on these telephone cables also showed a total of from 3 to 5 amperes flowing west, part of which current flowed from the underground to the overhead cables at Strathcona street. The lead sheaths of these overhead cables are connected to ground plates about every thousand feet, and are also grounded at many poles through the messenger cables and guy wires.

It is evident that these underground telephone cables were in very serious danger from electrolysis for a considerable distance east from Strathcona street. In fact a ground plate buried in the manhole at Strathcona street and connected to the cable sheaths for the purpose of draining off stray current to ground had already been completely destroyed by electrolysis, which makes it probable that the lead cable sheaths in this vicinity have also been affected by electrolysis. Stray current continuing west from Strathcona street on the overhead cables must also have left these cables through the ground plates and guy wires causing corresponding corrosion from electrolysis of these ground plates and guy wires.

In order to protect these telephone cables from electrolysis, it was decided to electrically drain these cables to the railway return conductors as a temporary relief measure. A number of tests to determine the most practical and safe method to accomplish this showed that the best results were obtained by connecting the sheaths of the underground telephone cables directly to the sheaths of the street railway cables at Strathcona street by a 105 500-cir. mil tie drainage connection averaged from 30 to 40 amperes during day load, flowing from the telephone to the street railway cable sheaths. In the St. James substation the current drained from the street railway cable sheaths increased however only from 5 to 10 amperes, when the tie connection at Strathcona street was closed. The increase in the drainage current in the St. James substation was therefore very much less than the current flowing in the tie connection from the telephone cables to the street railway cables at Strathcona street. This is due to the fact that with the telephone cable sheaths also drained to the street railway cables, some of the stray current formerly flowing to the street railway cables now flows to the telephone cables, so that the total stray current flowing directly to the street railway cables is reduced.

At my request, an underground 105 500-cir. mil copper tie drainage cable was installed at Strathcona street from the telephone cable sheaths to the street railway cable sheaths with a knife switch and a safety fuse connected in series and located in the telephone manhole.

The safety fuse is for the purpose of protecting the cables against excessive current. The Telephone Commission laid a fibre duct underground between the telephone and street railway manholes for carrying the tie cable, furnished and installed the knife switch and safety fuse, and connected the tie cable to the telephone cable sheaths. The street railway company furnished the tie cable and completed the installation. A current measurement in the drainage connection in the St. James substation after this tie connection was installed showed a total drainage current of from 40 to 60 amperes with average day load.

The effect of the tie drainage connection at Strathcona street was to lower the potential of the telephone cable sheaths to substantially the potential of the street railway cable sheaths, and to change the potential of these cable sheaths referred to the tracks from a highly positive condition to 1 to 3 volts negative to the tracks. There is therefore no longer any tendency for stray electric current to leave the underground telephone cable sheaths in this locality, so that these underground cables are now protected against corrosion by electrolysis. The effect of the tie drainage cable has also been to stop the former stray current which was flowing from the underground lead cable sheaths to the overhead lead cable sheaths and from these to ground plates and to guy wires west of Strathcona street. There is in fact now a slight current flowing from these ground connections to the overhead cables towards Strathcona street, so that the former danger of destroying the ground plates and guy wires by electrolysis has also been removed.

As the drainage connection from the street railway cables to the negative busbar in the St. James substation now also drains current from the telephone cable sheaths through the tie drainage connection at Strathcona street, a knife switch has been inserted at my request by the railway company in the drainage connection in the substation.

The tie drainage connection from the telephone to the street railway cable sheaths has somewhat raised the potential of the street railway cables because it has increased the current drained over these cables and over the drainage connection to the St. James substation. The total current drained has only been increased by 5 to 10 amperes during day load. These results indicate that the danger to the water pipes from electrolysis on Portage avenue has not been materially increased by the tie drainage connection from the telephone to the street railway cable sheaths at Strathcona street. This tie connection, however, renders the telephone cables in the region of the St. James substation as safe from electrolysis as can be practically accomplished under present railway conditions.

The City Light and Power Department does not have underground cables in the region of the St. James substation.

District of Main street and Inkster avenue railway substation: This substation was placed in service December 29, 1909. The negative

busbar in this substation is connected to the double tracks on Main street by large negative feeder cables. There are no other return feeders from the tracks to the substation. Government telephone cables are carried in underground conduits on the east side of Main street north to a point near the city limits. The lead sheaths of these telephone cables were found to be from 1 to 5 volts positive in potential to the street railway tracks at the corner of Main street and Athol avenue, and about one volt positive in potential to the water pipes. Stray railway current averaging about 4 amperes was also found flowing on these telephone cables on Main street at Bannerman avenue in a direction north. It appeared, therefore, that these telephone cables were in serious danger from electrolysis in the region of Athol avenue, which is close to the substation, so that it was decided to protect these cables in this vicinity by an electrical drainage connection to the negative busbar in the railway substation as a temporary relief measure. After some experimenting a 211 600-cir. mil drainage cable was installed from the telephone manhole on Main street and Athol avenue to the railway substation. A spare telephone duct from this manhole to a pole on Athol avenue was used for carrying this cable from the manhole to the pole, and the Telephone Commission connected the drainage cable to the lead sheaths of the telephone cables in the manhole. The railway company furnished the drainage cable and completed the installation to the negative busbar in the railway substation, with a knife switch in circuit placed in the substation.

A current measurement in this drainage connection showed an average of 18 amperes drained from the cable sheaths to the negative busbar during peak load. The potential of the telephone cable sheaths referred to the street railway tracks at Main street and Athol avenue was reduced by this drainage connection from its former highly positive condition relative to the tracks to a small reversing potential averaging about 0.1 volt. The potential of the telephone cable sheaths was also reduced by this drainage connection to nearly 2 volts negative to the water pipes at Athol avenue. On Main street, at Anderson avenue, which is a few blocks south from Athol avenue, the telephone cable sheaths were rendered 3 volts average negative in potential to the tracks and 0.3 volt average negative to the water pipes by this drainage connection. These measurements at Anderson avenue were also made during the peak-load hour. The installation of the drainage connection on Main street and Athol avenue has, therefore, removed the former danger to the telephone cables from electrolysis in this vicinity. In view of the fact that there is only one telephone cable on Main street, north from Anderson avenue, and as the total current drained from this cable is relatively small, I would not expect that the drainage of this cable has materially increased the danger to the water pipes from electrolysis. This is confirmed by the fact that current measurements made on the water main in Main street at Atlantic avenue did not show any change in this current when the telephone drainage connection at Athol avenue was opened and closed.

The City Light and Power Department does not have underground cables in the region of this Main street and Inkster avenue railway substation.

District of Assiniboine avenue and Garry street railway substation. —This substation was placed in service September 25, 1912. In the building with this substation there is a direct-current steam engine plant which was formerly used to supply power for the electric railways of Winnipeg. This steam plant is not in use at present. The double tracks on Main street betweeen Assiniboine avenue and the river are connected to the negative busbar in this substation by overhead return feeder cables. The double tracks on Broadway are also connected to the negative busbar in this substation by weatherproof return feeder cables laid in conduits in Garry street. A number of return feeders from this substation also parallel the tracks on Main street; these connect with the return feeders on Main street from the Mill street substation. Return feeders paralleling the tracks also continue south on Main street and west on River avenue.

Government telephone cables are carried in underground conduits on Main street south to the Assiniboine River. From here these cables continue south overhead over the bridge. Potential measurements of the telephone cables on Main street near Assiniboine avenue showed that the sheaths of these cables were from 1 to 2 volts positive in potential to the tracks, and that at York avenue, which is two blocks north from Assiniboine avenue, these cables carried substantial stray electric currents flowing in a direction south. On Broadway near Garry street the telephone cables were negative to the tracks. The underground telephone cables on Main street were, therefore, in danger from electrolysis due to these stray electric currents in this vicinity. In order to protect these cables against this danger, a 105 500-cir. mil copper drainage cable was installed from the cable sheaths on the pole on Main street at the river, to the negative busbar in the railway substation, with a knife switch in circuit placed in the substation. This installation was made by the railway company. A current measurement in this drainage cable showed an average of 9 amperes drained from the telephone cables to the negative busbar. The former potential of from 1 to 2 volts positive to the tracks was thereby reduced to a reversing potential of about 0.2 volt. The telephone cables with this drainage connection installed also became about one volt negative to the water mains. These telephone cables have, therefore, been protected against destruction by electrolysis. Since the current drained from these cables is very small, I do not believe that this drainage connection has materially increased the danger of the water pipes in this region from electrolysis.

In Assiniboine avenue there are two arc light cables supplying arc lamps on Assiniboine avenue, one being laid on each side of the street. These cables pass by the railway substation and cross the ducts containing the return feeders going to Broadway avenue. It was found that during day load these arc light cable sheaths were 3.5 volts average

positive to these return feeders, and 3.2 volts average positive to the water pipes. These arc light cables were, therefor, in danger from electrolysis at their points of crossing with water pipes and with these return feeders.

A temporary 105 500-cir. mil drainage connection installed from the arc light cable sheath on the south side of Assiniboine avenue to the negative busbar in the substation resulted in rendering the arc light cable sheath on the north side one volt positive in potential to the cable sheath on the south side. A similar drainage cable was, therefore, carried from the arc light cable sheath on the north side of Assiniboine avenue and connected to the drainage connection from the arc light cable on the south side. This cable was then connected to the negative busbar with a knife switch placed in circuit in the substation. The drainage cables which were connected to the arc light cables were laid from the arc light manholes to ducts of the street railway company by the City Light and Power Department, and the street railway company then completed the installation.

A current measurement in this drainage cable showed an average of 7 amperes drained from these arc light cables with average day load. The potential of these cables was reduced to 0.2 volt positive to the return feeders and 0.7 volt negative to the water pipes by this drainage connection. These tests show, therefore, that the drainage of these arc light cables has substantially removed the danger from electrolysis to which these cables were previously subjected in this region. As there is only a single arc light cable on each side of the street which is small in size and, therefore, presents a relatively small surface to earth, and since the total current drained is relatively very small, I do not expect that the draining of these arc light cables has materially increased the danger to the water pipes from electrolysis.

District of Logan avenue and McPhillips street railway substation. —This substation was placed in service November 18, 1912. The negative busbar in this railway substation is connected to the double tracks on Logan avenue by large negative feeder cables. There are no other return feeders from the tracks to the substation. Three 13000-volt lead covered cables of the City Light and Power Department are carried in underground conduits on Higgins avenue west to the substation at McPhillips street. These cables cross street railway tracks on McPhillips street, and it was found that these cables were from 2 to 5 volts positive in potential to these tracks. A total current of 0.18 ampere was also found flowing west on these cable sheaths at a point east from McPhillips street. These cables, therefore, appeared to be in danger from electrolysis where they cross the street railway tracks on McPhillips street.

In the city light and power substation these three cable sheaths are bonded to a common ground wire which also connects to the lead sheathing of a large number of arc light cables which are carried underground to the east side of McPhillips street at Higgins avenue, and to

the southeast corner of Logan avenue and McPhillips street, where these arc light cables are carried up poles and continue overhead.

In order to protect the 13000-volt cables against danger from electrolysis, a 105 500-cir. mil copper drainage connection was installed. from the common ground wire in the city light and power substation to the negative busbar in the railway substation, with a knife switch in circuit placed in the railway substation. The City Light and Power Department connected the drainage cable to the ground wire and carried this wire out of the substation to a pole on McPhillips street; the railway company furnished the drainage cable and completed the installation. A current measurement in this drainage cable showed an average of 14 amperes drained from the city light and power cables to the negative busbar in the substation. A drop test on the ground wire on each side of the point where the drainage cable is connected, showed that 13.7 amperes of this current comes from the cable sheaths of the three 13,000-volt cables, and 0.3 ampere from the other cables connected to this ground wire. It, therefore, appears that practically all of the current drained from this ground wire comes from the cable sheaths of the three 13,000-volt cables. The potential of the 13,000-volt cable sheaths was reduced by this drainage connection from its former highly positive potential to the tracks to about 0.2 volt reversing in polarity. These cables have, therefore, been rendered safe from electrolysis by this drainage connection. As the total current drained from these cables is relatively small, I would not expect that the danger to the water pipes from electrolysis has been materially increased by this drainage connection, and it seemed imperative to protect the high tension cables in the manner described.

District of Mill street railway substation.—This substation was placed in service June 11, 1906. The nearest street railway tracks are located on Main street, which is about 1,200 feet from this substation. At the corner of Main street and Portage avenue, the double tracks on Portage avenue and on Main street connect together, and just west of Main street the double tracks from Notre Dame avenue also connect to the tracks on Portage avenue. The various tracks near this corner of Main street and Portage avenue are electrically connected together by heavy copper jumper cables; these tracks are also connected through underground weatherproof return feeder cables, having an area of approximately fourteen million cir. mills, to the negative busbar in the Mill street substation. A number of return feeders also continue for some distance north and south on Main street, tapping into the tracks at many points, thus serving as parallel conductors to the tracks on Main street. The lowest potential point in the track system in the Mill street substation district is, therefore, at the corner of Portage avenue and Main street. In the course of the tests made during June and July last, howover, I found that the negative busbar in the Mill street substation was grounded through accidental contacts between iron conduits or pipes and return feeder cables thereby rendering the ground at the Mill street substation from 4 to nearly 7 volts lower in potential than the earth at Portage avenue and Main street, this being the voltage drop in

the negative return feeders from this point. As this increase in voltage drop through ground due to this grounding of the negative busbar increased the total stray currents, and in fact had already caused destructive pitting from electrolysis of an iron conduit and the lead sheathing of a fire and police telegraph cable in this conduit, I requested to have this busbar cleared of all grounds. This was done during the summer, with the result that the ground at Mill street is now substantially at the same potential as the ground at Portage avenue and Main street.

The electrical drainage connections installed several years ago to protect the Manitoba Government Telephone cables in this Mill street substation district consists of two 336 000-cir. mil weatherproof cables carried between a telephone manhole and a street railway manhole in Portage avenue east opposite the Main telephone exchange; these drainage cables are connected to the lead sheaths of all of the cables in the telephone manhole, and to the railway return feeders in the street railway manhole. A 24-hour record of the current flow in these two drainage connections showed that a total all-day average current of 230 amperes was drained from these cable sheaths to the railway return conductors.

Two electrical drainage connections had also been installed for the protection of the street railway cables; one of these consisted of a 336 000-cir. mil weatherproof cable connected to the lead sheaths of the street railway cables at the corner of Portage avenue and Main street, and carried in underground conduits, together with the return feeders, to the negative busbar in the Mill street railway substation. The second of these drainage connections consisted of one 211 600-cir. mil cable from the street railway cable sheaths in the manhole directly in front of the railway substation to the negative busbar in this station. The all-day average current drained from the cable sheaths at Portage avenue and Main street was 72 amperes, and from the cable sheaths at the Mill street substation 93 amperes, making a total of 165 amperes drained from these street railway cables. A 2-inch Pintsch gas pipe is laid in the right-of-way of the Winnipeg Transfer Railroad Company. A 211 600-cir. mil drainage cable was also connected to this gas pipe near Lombard and Mill streets and carried in underground conduits to the negative return feeders in the substation. The all-day average current drained from this small gas pipe was 66 amperes. The total current drained from the telephone and the street railway cable sheaths, and from this Pintsch gas pipe was, therefore, 461 amperes. The all-day average load of the Mill street substation was approximately 3320 amperes, so that the total current drained from these telephone and street railway cable sheaths and from this one small Pintsch gas pipe was 14 per cent. of the total station load.

The drainage connection from the street railway cable sheaths directly at the Mill street substation was installed in addition to the drainage connection from the same cable sheaths at the corner of Portage avenue and Main street, because the former grounded condition

of the negative busbar endangered the street railway cable sheaths in Mill street from electrolysis, even after they were drained at Portage avenue and Main street. The drainage connection from the Pintsch gas pipe was likewise installed largely because of this grounded condition of the negative busbar in the Mill street substation. With this busbar insulated from ground directly at the substation, as at present, there is no longer any need for these drainage connections at Mill street, and in fact they are undesirable because they add to the danger of other underground structures.

At my request knife switches have been installed in each of the electrical drainage connections in the neighborhood of the Mill street substation so that these drainage connections can be opened or closed when desired.

At the corner of Portage avenue and Main street, there are high and low-pressure water pipes belonging to the City of Winnipeg, gas pipes and underground cables belonging to the Winnipeg Electric Railway Company, underground cables belonging to the Manitoba Government Telephone Commission, underground cables belonging to the City Electric Light and Power Department, and underground cables belonging to the City Fire and Police Telegraph Department. The fire and police telegraph cables are generally carried in the telephone conduits, and in each manhole all of the telephone cable sheaths and the fire and police telegraph cable sheaths are bonded together. The city light and power cables are carried in independent conduits, and the sheaths of all their cables are bonded together in every manhole. The street railway cables are also carried in independent conduits, and these cable sheaths are bonded together in every manhole.

With all drainage connections from the street railway cables and from the telephone cables closed, potential measurements were made at the corner of Portage avenue and Main street, with average day load, and these gave the following average values:

Street railway cables—0.8 volt negative to tracks;

Man. Gov. Tel. cables—0.4 volt positive to tracks;

Man. Gov. Tel. cables—1.2 volts positive to street railway cables;

City Light and Power cables—1.0 volt positive to tracks;

City Light and Power cables—1.8 volts positive to street railway cables;

Low-pressure water pipes—0.6 volt positive to tracks;

Low-pressure water pipes—1.4 volts positive to street railway cables;

Low-pressure water pipes—0.05 volt negative to high-pressure water pipe.

When all the drainage cables were temporarily disconnected, the water pipes, and the lead sheaths of the telephone, the city light and power, and the street railway cables, were all practically at the same

potential, and 3.8 volts average positive to the tracks. The fire and police telegraph cables are included with the telephone cables in these tests, because in this region they are bonded to the telephone cables and are, therefore, of the same potential as the telephone cables.

It will be noted that the drainage connections to the telephone and street railway cables reduced the potential of the telephone cables from 3.8 volts to 0.4 volt positive to the tracks, and reduced the street railway cables from 3.8 volts positive to 0.8 volt negative to the tracks. This very low potential condition of the street railway cables is due to the drainage connection to the negative busbar directly at the Mill street substation.

The fact that the drainage connections of the telephone and street railway cables also reduced the potentials of the water pipes and of the city light and power cables, indicates that there are connections between all of these cables and water pipes. A few scattered connections from the city light and power cables to the fire and police telegraph cables and through these to the telephone cables are known to exist in police signal boxes, where cables from both systems enter and are connected together. A few connections from fire and police telegraph cables to water pipes also exist at police stations, where the fire and police telegraph cables are grounded to water pipes. There are, however, undoubtedly many accidental connections between various cable sheaths and water pipes through house service connections through which there may be a large interchange of stray railway current.

With all of the drainage connections closed, the negative potential of the street railway cables increases on Portage avenue west from Main street, so that the water pipes and other cables become correspondingly more positive to the street railway cables. It is, therefore, evident that in spite of the large current drained from the telephone and street railway cables, the potential conditions produced were not even satisfactory for the safety of the telephone cables.

A considerable number of potential measurements were made with the drainage connections from the street railway cables at Mill street disconnected, leaving the drainage connections of the telephone cables and of the street railway cables at Main street and Portage avenue connected. With this arrangement, the street railway cables were about one volt less negative in potential in Portage avenue at Main street and west of Main street, than with the drainage connection at Mill street closed, so that considerable improvement would be made by maintaining this drainage connection open. This will not endanger these cables in Mill street because the negative busbar is now insulated from ground so that the ground at Mill street is no lower in potential than the ground at Main street and Portage avenue.

In order to determine whether it would be practicable to improve the potential conditions of the various cable systems in the region of this Mill street substation, particularly the condition of the city light

and power cables, extensive tests were made by temporarily tying the various cable systems together at the corner of Portage avenue on the east side of Main street. At this corner, manholes containing city light and power cables, telephone cables, and street railway cables, are close together. In this street railway manhole the cable sheaths are connected to the drainage cable.

A test was first made with a 105 500-cir. mil copper tie cable from the city light and power cables to the telephone cables in the adjoining manhole, and from there to the street railway cables in the next manhole. *These tests were made under average day load conditions. It was found that an average current of* 125 *amperes flowed in the tie connection from the city light and power cables to the telephone cables, and an average current of* 150 *amperes in the tie connection from the telephone cables to the street railway cables.* The potentials between the various cable systems were then measured with this tie cable connected. It was found that on Portage avenue east at Main street, that is directly at the tie connection, the city light and power cables were still 0.9 volt positive to the street railway cables, and at Carlton street, the city light and power cables were 1.2 volts positive to the street railway cables. It was, therefore, evident that the tie cable did not have a sufficiently low resistance to be effective in reducing the potentials between the various cables to satisfactory values. A second test was, therefore, made, using a 500 000-cir. mil tie connection in place of the one previously used. *It was found that an average current of* 160 *amperes flowed in this tie connection from the city light and power cables to the telephone cables, and an average current of* 230 *amperes from the telephone cables to the street railway cables.* The various cable systems were hereby brought within 0.5 volt of each other in potential near this tie connection. At Portage avenue and Carlton street, however, the city light and power cables were still about 0.9 volt positive to the street railway cables, and the telephone cables were about 0.7 volt positive to the street railway cables. *These potential conditions were somewhat improved but were not rendered satisfactory* when the drainage connection from the street railway cables at the Mill street substation was opened.

The above tests indicate quite clearly that to bring the potentials of the various cable systems to practically the same values at Portage avenue and Main street would require tie connections of still larger cross-section than used in these tests. As already stated, the current flow from the city light and power cables through the 500 000-cir. mil tie drainage connection was 160 *amperes under day load conditions, and this with peak-load conditions would become very much larger.* A larger tie drainage cable would cause a still larger current to be drained from the city light and power cables. The total current drained from the cables in this district would be increased by such a tie connection but not by the amount of current flowing over the tie connection, because the latter current would come not only from the city light and power cables, but also from other cables and from pipes, through

metallic contacts between them. *The drainage of such large currents from the city light and power cables would, therefore, involve the danger of large interchange of current between various cables and pipes at new and unknown points of contact, and these would undoubtedly exist largely between services in buildings, where such currents would constitute a fire hazard.* I am, therefore, of the opinion that it *would not be safe to apply drainage to the city light and power cables, nor to add to the drainage of the telephone cables, nor to bring all of the cables at Portage avenue and Main street to the same potential by a sufficiently large tie connection.* All of the cable systems, including the city light and power cables, are already partially protected through the drainage connections from the telephone cables and the street railway cables through contacts between the lead sheaths of these cables which evidently exist.

When the telephone and street railway drainage connections were opened, the cables were all nearly 4 volts positive to the tracks at Portage avenue and Main street with day load. In a telephone manhole at Portage avenue east and Main street, with this drainage open, a total current of 24 amperes was also found on 18 cable sheaths, and there were 12 more cables in this manhole, which could not be reached for test. It is, therefore, evident that with present electric railway conditions, drainage connections are needed for the protection of these cable sheaths in the vicinity of Portage avenue and Main street. I would, therefore, suggest that the present drainage connections from the Manitoba Government Telephone cables at the main telephone exchange in Portage avenue, and the drainage connections from the street railway cables at Portage avenue and Main street, be continued, but that at least for the present no further drainage connections be made in this district.